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MILTON WHITNEY, Chief.

THE CHEMISTRY OF THE SOIL AS RELATED TO CROP PRODUCTION.

BY

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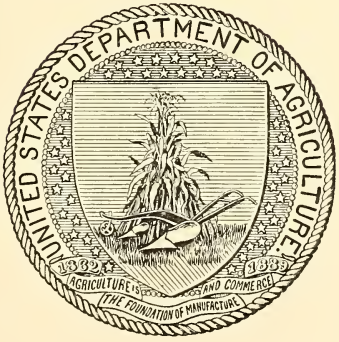

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., July 31, 1903.

Sir: I have the honor to transmit herewith the manuscript of a report on the chemistry of the soil as related to crop production. I recommend that this report be published as Bulletin No. 22 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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THE CHEMISTRY OF THE SOIL AS RELATED TO CROP PRODUCTION.

GENERAL DISCUSSION.

The objects to be attained in the management of a soil are the determination of the crop or crops adapted to it, the regulation of the yield, and the control of the quality of the product.

The investigations made by the Bureau of Soils during the last ten years have shown that the economic distribution of crops is dependent mainly upon the physical characteristics of soils and upon climate. It has been believed that the chemical characteristics of soils have a more or less direct and controlling influence on the yield of a crop on any particular soil; that is to say, where wheat yielded 10 bushels per acre in one field, and in an adjoining field (the soil of which had the same texture, so far as could be determined, although it might be in a better physical condition) 25 or 30 bushels were obtained, this difference in yield would be found to be due to or associated with a difference in the amount of available plant food in the soil of the two fields. It was believed, further, that the better physical condition resulting through loosening up and aerating the soil and exposing it to the weathering influence of the atmosphere by better and more thorough methods of cultivation would in itself prepare a larger amount of readily available food material for the use of crops.

These two subjects, distribution and yield, are both of vital importance to the farmer; but while the yield of crops has been a study for the experimenter and farmer alike throughout historic times, too little attention has been paid by him to the adaptation of particular soils to crops. The yield is to-day the paramount question with the farmer, and all his energy and resources in the last analysis tend to this end.

The third object mentioned above, the control of the quality of the crop, while beginning to receive more attention in general agriculture, is a subject which has been of importance up to the present only in special lines of agriculture, such, for example, as the production of the different grades of tobacco. It has been given particular attention by the horticulturist in improving the flavor and coloring of fruits and has been studied in the highly developed industry of floriculture in

attempts to control the color, perfume, shape, time of maturity, or other desirable quality of flowers. In such specialized agricultural and horticultural industries, where fertilizers are used to control the quality of crops, it is always considered a necessary prerequisite that the soil be put in the most perfect physical condition for the crop. The assumption that the soil is in such perfect physical condition in general field culture can never be safely made. This is an important distinction which must be borne in mind in following the argument set forth in this bulletin.

The subject of the effect of the chemical characteristics of a soil upon the quality of a crop has not as yet been taken up by the Bureau; but the yield of crops, the matter of prime importance to the farmer, has been made the subject of an exhaustive research, the results of which and the conclusions based thereon are given in the following pages.

The investigations reported in this bulletin seem to necessitate an interpretation of the influence of the chemical characteristics of soils on the yield of crops somewhat different from that usually advanced, and modify very materially our conception of this important matter.

The classification of soils in the soil surveys made by this Bureau is based mainly upon physical differences, consideration being given, also, to location, elevation, exposure, and, in a more limited degree, climatic conditions. The fact that the soil maps are constructed in the field is itself evidence that the classification is made upon physical characterictics apparent to a trained observer. The classification is thus supposed to indicate soils requiring for their most profitable use different methods of cultivation, or for other reasons more or less adapted to different kinds of crops.

The chemical characteristics of soils have had little recognition in soil classification or mapping by this Bureau, from the fact that the ordinary methods of determining the plant foods which a soil contains have not given results apparently related in any definite way to the yield of crops. For many years chemists have been working on this problem of the relation of the chemistry of soils to crop production, both through exhaustive series of analyses of soils and plants and through fertilizer experiments on the land; but in comparatively few instances have any results been obtained which show conclusively that a given fertilizer is required by a certain soil, and that equally favorable, or in fact the same kind of results, would be obtained under changing climatic conditions from year to year.

It frequently happens that the application of a certain fertilizer, or more properly fertilizer ingredient, may give a marked increase in the crop, while the next year the same application will give negative results or may apparently reduce the yield below that obtained from the unfertilized soil. It is also a matter of common experience that in a certain

season one variety of corn or potatoes, for example, may do better on a soil and in another season another variety of the same crop may give the better results. Furthermore, it is well known that, as a rule, the influence of the climate has an effect upon the yield greater than that due to the different fertilizers, while in a great many cases the effect produced by the character of the cultivation and cropping of the soil is much more marked than that produced by any fertilizer that may be used. In its broadest sense, the term climate may be applied both to atmospheric conditions and to soil conditions, for the soil which will maintain the most abundant supply of moisture has to all intents and purposes a different climate from one which will not only actually maintain a smaller percentage of water, but will also supply a smaller amount as compared with the need of the crop.

In considering the question of the chemistry of the soil as related to crop yield, it seemed important to determine what amount and proportion of the several plant foods were actually in solution in the soil at any one time, or from time to time. It was evident that a solvent, which attacks more vigorously than does water the different mineral ingredients of the soil, would not give results necessarily in proportion to the amount of these ingredients of which a plant could avail itself. In the use of solvents, whether concentrated acids or dilute acids, whether mineral acids or organic acids, one apparent justification lies in the supposition that the effect of the solvent was analagous to the action of the plant in itself dissolving and preparing its food material from the mineral matter of the soil. Such an assumption is hardly warranted by the known facts, nor does it seem necessary to assume that the plant has, of itself, power to dissolve its mineral food from the solid particles of soil. It seems altogether more reasonable to believe that, as all such food is taken into the plant through solution, the soil moisture constitutes a nutritive solution in which the plant normally finds its food supply, just as animals find their food in the native vegetation without any necessity for preparation before taking it into their systems. Another justification claimed for acid digestion is the supposed, but unproved, assumption that the acid will extract the amounts, or definite factors of the amounts, of plant food available during a growing period. That such a supposition must be vain is seen to be likely, considering the great changes brought about by variations in climate, in local conditions, in seed, or in cultural methods.

Many chemists have in the past considered this question, whether or not the water extract of a soil would represent the food material of the plant, and, while admitting that an extract so prepared, or that well waters and drainage waters—which are natural extracts of the soil—would under suitable conditions support a crop of normal size, yet, as they could not find differences in soils that would account for the differences in yields, they were led to believe this method inadequate for

the determining of the true relation between soils and crops. Furthermore, with the chemical methods then available, it was realized that the small amount of plant food contained in a soil extract could not be determined with sufficient accuracy to justify the formation of any definite conclusions.

In taking up the question of the relation of the chemistry of the soil to crop production, the Bureau of Soils has again investigated this old idea of examining the water extract and has developed very sensitive and rapid chemical methods for the estimating of minute quantities of mineral matter in solution.

The results have satisfied us that the soluble mineral matters of soils produce in general a saturated or nearly saturated solution in the soil moisture; that is, that the mineral substances containing the lime, potash, and phosphoric acid, for example, are for the most part complex and but slightly soluble materials, of which only a small proportion could at one time be dissolved in an amount of water represented by the normal water content of soils. And the indications point to the fact that the potash, for instance, is not in general present as a common salt, such as the chloride or sulphate, but exists probably in the form of a complex mineral not necessarily identical with any known mineral substance.

The microscopical examination of soils shows them to be made up for the most part of quartz, feldspars, and micas, decomposition products of these minerals, and to a much less extent of other common rock-forming minerals. But as mineralogists rely mainly upon the crystalline structure of a material for the determination of its mineral character, there are probably many substances which through lack of crystallization, or from the fact that they occur in small amounts, have never been recognized or determined by mineralogical methods.

These mineral substances are nearly all salts, in fact, with generally slight solubilities in water. And the quantity of a constituent, as, for example, potassium, which can possibly enter the solution is necessarily small because determined by definite equilibrium conditions with the but slightly soluble mineral from which it is derived.[a] This does not mean

[a] See Application of the Theory of Solution to Soil Studies, Report No. 64, Division of Soils, U. S. Dept. Agr., 1899, and Field Operations of the Division of Soils, 1900; also The Nature and Function of Soil Solutions, Bul. No. 17, Division of Soils, 1901, U. S. Dept. Agr.

The saltlike nature of our common rock-forming minerals and some of the chemical effects which mineral fertilizers may exert upon them are illustrated in certain experiments that have been carried on in the laboratory of the Bureau of Soils, of which a few might be cited appropriately in this connection. If a potash feldspar (such as microcline) or a potash mica be powdered, so as to expose a large surface for action, and then be treated with water, it will go into solution to some extent and the base be hydrolized to the hydrate, its presence being readily detected with

that more potassium could not be dissolved in the solution, as by the addition of a highly soluble potassium salt. But since it seems quite probable that synthetic as well as destructive processes may take place within the soil, it may very well happen that the addition of comparatively small amounts of a readily soluble potassium salt to a soil would simply force back the dissociation and solubility of the potash minerals, with no consequent gain of potassium to the soil solution.[a]

The ultimate origin of all soils is presumably the igneous rocks, but there are relatively small areas of soil existing at present, derived directly from such rocks in place. The vast majority of our soils are

phenolphthaleine, as has been pointed out by the Rogers (Am. Jour. Arts and Sciences, 1848), Clarke (Jour. Am. Chem. Soc., **20**, 739, 1898), and this Bureau (Bul. No. 17, Division of Soils, U. S. Dept. Agr., 1901). If, however, a readily soluble potassium salt, such as the chloride or the sulphate, be added, the hydrolysis and dissociation of the base will be forced back and the solubility of the mineral decreased, as can readily be detected by the diminished color obtained with phenolphthaleine. On the contrary, the presence of sodium salt, such as the nitrate, which does not yield a common ion, increases the solubility of the mineral. Serpentine, a magnesium mineral salt with a relatively high solubility, is especially well adapted to demonstration of this point, and similar qualitative tests have been made with most of our common rock-forming, and at the same time base-carrying, minerals, showing conclusively that they are salts of strong bases with weak acids, and conduct themselves toward water as would any salts of this character. But while these experiments (which can be easily reproduced by anyone, and seem admirably adapted for lecture-room demonstrations) satisfactorily demonstrate that the majority of our minerals are salts, it is not always safe to predicate *a priori* their conduct toward solutions of other salts, since several cases are now known where the addition of a salt which does not yield a common ion fails to increase the solubility. For instance, it is commonly believed that much of the phosphoric acid which soils contain is in the form of aluminum or ferric phosphate, but careful solubility determinations, which this Bureau will shortly publish, show that these particular salts prepared artificially by precipitation are less soluble in aqueous solutions of several of our common salts than in pure water, although as far as our knowledge extends no common ion is formed. Furthermore, very careful measurements on the solubility of the two phosphates mentioned, as well as some calcium phosphates, in pure water, show that considerble hydrolysis takes place, and that it is dependent upon the proportion of the relative masses of the solid salt and the water present, not being independent of the amount of solid phase so long as it does not disappear. In every case the resulting solution is acid, even with tricalcium phosphate, thus confirming the observation of Warrington [Jour. Chem. Soc., **19**, 304 (1866)], although in this last case we should certainly have expected just the opposite result. While the dissociation hypothesis is fertile in suggestions for work in this field, it can never be safely used in argument unless fortified with the results of direct experiment.

[a] Very suggestive in this connection are some observations which have been made in the laboratory of this Bureau, and in illustration of which a case will be cited. A large sample of water was taken from the Potomac River when in flood and carrying much suspended silt and clay. This was filtered through a Chamberland-Pasteur filter to remove the suspended material. The filtrate was then regarded as a soil solution or extract. To a portion of the filtered river water salts were added so that 5 parts per million of potassium (K) and the same amount of nitrates (NO_3) were

of sedimentary origin, and have been derived from the decomposition products of the igneous rocks transported by water, wind, or glaciers, and redeposited, often at great distance from their source. These soil materials removed from the area occupied by the crystalline rocks of the Piedmont Plateau, for example, and spread out through the agency of water over the Coastal Plain, contain the same aggregations of quartz, feldspars, and micas, and other associated minerals, as did the original rocks, though in different proportions. Since practically all these minerals and their decomposition products are present in all soils, and since the absolute solubilities are in general small, although relatively they may be considered as varying quite widely, it seems reasonable to expect that the soil solution or the soil moisture will in

introduced, and at the same time a similar solution was made, using pure distilled water. The two solutions thus prepared, with a portion of the filtered but otherwise untreated river water, were then stored for several days in Winchester quart bottles, which had been long in use, and had consequently a very low solubility. Analyses of the three samples yielded the following results:

Samples.	Parts per million of solution.			
	Potassium (K).		Nitric acid (NO_3).	
	Calculated.	Found.	Calculated.	Found.
River water		7.1 7.3		3.3 3.5
River water with salts added	12.2	8.0 7.8	8.9	10.5 10.7
Distilled water with salts added	5.0	5.7 6.4	5.0	5.4 5.0

The check figures obtained from the solution made with distilled water indicates that the method of examination was satisfactory and that probably the glass of the bottle had little part in determining equilibrium. It seems safe, therefore, to conclude that while the added nitric acid could be readily recovered from the river water or soil solution, such was not the case with the potassium. Whether the latter separated from the solution as a solid phase in combination with other constituents we can not yet say. The amount of such phase in the comparatively large volume of water present would probably be entirely too small to be observed by the eye. The subject will be carefully investigated in the future by chemical methods. On the other hand, much has appeared in our recent studies suggesting the possibility that some of the constituents of a soil solution, as the potassium in this case, may sometimes enter such combinations, or such more or less complex "ions" as not to be responsive to our ordinary testing reagents. It is of course an open question whether these constituents, if so combined, would be available to the plant as nutrients.

But it must not be supposed that the solution in soils under certain conditions can not be materially changed, as, for instance, in the experiments described in this bulletin upon the effect of drying and rewetting without drainage. Whether or not the solution in these soils so treated would, on long standing, return to approximately the same conditions of concentration and composition as that in the untreated soils is being investigated now.

all types of soil be of the same order of concentration and composition. It is recognized that exceptions do exist, and that there are soils which are probably composed of such a mixture of mineral substances as would yield a soil solution differing widely in character and concentration from that normally to be found in cultivable soils. Moreover, bacterial agencies, such as nitrifying organisms, ferments, etc., and local conditions may be expected to produce unusual results. Such cases are, however, to be regarded as abnormal.

Briefly stated, the results given in the following pages appear to show, contrary to opinions which have long been held, that there is no obvious relation between the chemical composition of the soil as determined by the methods of analysis used and the yield of crops, but that the chief factor determining the yield is the physical condition of the soil under suitable climatic conditions.

AVAILABLE AND NONAVAILABLE PLANT FOOD.

The chemical analysis of a soil by digestion in an acid or a salt solution generally shows a greater amount of plant food in the soil than would be required for plant growth, and hypotheses, varying in details, have been advanced to the effect that a portion of this plant food was immediately available, available during a growing season, ultimately available in the course of years, etc. A great deal of energy and ingenuity have been displayed in attempting to find procedures along chemical lines and with various solvents which would yield quantities corresponding to some one of these various classes of "available" plant food. Considering the number of factors entering into plant growth other than the solvent action of the media employed, such as the physical and chemical characteristics of the soil, seasonal and climatic influences, differences in the requirements of different crops and varieties of a crop, such attempts, as far as furnishing any data as to the specific requirements of crop yield is concerned, will probably be vain in the future as they have been in the past.

The underlying premise in all such methods, though not always specifically set forth by their proposers, is that plants have the power within themselves, either by excretions from their roots or otherwise, to dissolve mineral plant foods from the soil grains. The seemingly positive evidence in regard to this is found in the old experiments on the etching of limestones and certain sandstones by plant roots, but it is significant that in all of the experiments that have been reported the etching has taken place on substances that would be dissolved to a certain extent by carbonic acid, and have not been observed on aluminum phosphates or similar materials which are not attacked by carbonic acid. Hence this evidence really appears to have little value,

as the same effects would have been produced by carbonated waters; and it is known that the atmosphere around the plant roots and in all soils is highly charged with carbonic acid.[a]

Another thing that has led chemists to believe that plants may directly or indirectly dissolve mineral matters of the soil is the observations that have been made in water-culture experiments in which the solution after a time becomes slightly acid. It has been held that this is due to an actual exudation of acids from the roots in their supposed function of dissolving plant-food material, but it has been shown that this is just as probably due to the fact that plants have a selective power and take up proportionally more of the bases than of the acids, leaving the excess of the latter in solution.

Pfeffer has remarked, however, that there are probably as many cases where the solution is left alkaline,[b] especially where there is present a considerable quantity of nitrates, as the plant in this case may take up more of the acid constituent than of the base. It would thus appear that this selective absorption of the plant is not related in any way to, or is it necessary for, the solution and preparation of its food. It would seem on the whole that the evidence is purely negative as to whether plants do or do not actually excrete acid other than carbonic acid, nor is it necessary to assume this excretion to provide a mechanism for the absorption of the plant food from the soil.[c]

It has been found also, from a consideration of the vast number of ash analyses that have been made, that no certain relation can be found between the ash of the plants and the results of the analyses of soils.[d]

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[a] The discussion of the significance of etched figures is very interestingly presented by Pfeffer (Physiology of Plants, Vol. I, p. 171 et seq., translated by A. J. Ewart, 1900), who considers not only the early work of Sachs and other investigators, but the more recent and very thorough work of Czapek [Jahrb. für wiss. Bot. **29**, 321, (1896)]. It is concluded that while there is satisfactory evidence that lichens and some other plants, even of higher species, can excrete acids from their roots, there is no reason to believe that the majority of our cultivated plants excrete anything of this kind other than carbonic acid, and that the assumption of such excretions is by no means necessary for the explanation of the mechanism of nutrition. The remarkable work of Spring [Zeit. physikal. Chem., **4**, 658 (1889)] on the action of carbon dioxide upon calcium carbonate and similar substances in contact with less soluble substances and the greater chemical activity at the surfaces of substances is of especial significance here, for he shows that the solution or etching effect is always much greater at the region of contact than elsewhere. Quite recently Kossowitsch [Ann. de la Sc. Agron., 2 ser., **1**, 220, (1903)] has considered this same subject in an experimental investigation, reaching conclusions in full accord with those just stated.

[b] Witness the classical experiments of Stohmann, Sachs, and Knops, cited by Johnson, How Crops Grow, p. 180.

[c] A discussion of this subject by Cameron from the view point of modern chemistry will be found in Report No. 71, U. S. Dept. Agr., p. 66 et seq., 1902.

[d] See in this connection the recent publication of Tollens, The Ash Constituents of Plants; Their Estimation and Their Importance to Agricultural Chemistry and Agriculture. Experiment Station Record, **13**, 206, 305 (1901).

The quantity of mineral matter taken up by the plant is dependent to such a large extent upon the climatic conditions, physical conditions of the soil, and physiological factors, upon the variety of seed and other circumstances, the exact influence of which can not be estimated, that in any formal expression of the relation between crop needs and soil fertility deductions based upon ash analyses can only be of the most general or uncertain value, and have frequently been shown by experience to be misleading.

Birner and Lucanus[a] long ago pointed out that plants can be grown to perfection in well water, if suitable physical conditions are preserved, and, as a matter of fact, they grew oat plants in such water renewed weekly, the yield of grain being double that from a rich garden soil. This well water contained in 100,000 parts 15.14 parts of lime, 2.13 parts of potash, 0.16 part of phosphoric acid, 7.45 parts of sulphuric acid, and 6.02 parts of nitric acid, so that the plant obtained all its needed phosphoric acid from a solution containing 1.5 parts of acid in 1,000,000 parts of water, a concentration probably less than that usually existing in the soil moisture. (See page 39.) Johnson, in commenting upon this experiment,[b] says: "The analysis of the well water shows that the nutritive solution need not contain the food of plants in greater proportion than occurs in the aqueous extract of ordinary soil."

In water-culture experiments the proportion of solid matters is usually maintained at between 0.5 and 2 parts in a thousand of water, and no observations have indicated any material difference in the yield within these limits, although above or below these concentrations crops may suffer.

Since it has been found that plants grow well and produce normal crops with the water-soluble constituents of the soil, it seems entirely unnecessary in studying the question of the nutrition and yield of crops to introduce artificial digestion media known to attack minerals very slightly soluble in water, while it seems perfectly logical to accept the nutrient solution as it exists in the soil as the basis for the support of plant life and to investigate the question along this line. In other words, it has seemed best to consider the soil as a culture medium containing a nutrient solution—that is, to regard the soil moisture as a proper and sufficient medium for the feeding of plants, and the soil as a reservoir and distributing agent for this solution.

The main justification in the past for an acid digestion of a soil has been the absence of satisfactory chemical methods by which to estimate with any degree of accuracy the small quantities of the plant foods extracted from the soil by any reasonable amount of water. This difficulty has now been met, as will presently be shown in the description of the chemical methods used by the field parties of the Bureau of Soils.

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[a] Landwirthschaft. Versuchssts. 8, 128 (1866). [b] How Crops Feed, p. 322.

CHEMICAL METHODS.

Many methods have been tried in the Bureau for extracting the moisture more or less completely from the soil, but the difficulty in the way, either mechanical or that due to the enormous force of capillary attraction existing in soils, seems at present insurmountable. The method adopted for the chemical work about to be described must, therefore, of necessity be a conventional one, but it is believed that at least comparable results can be obtained.

But one method has yet been suggested by which the actual aqueous solution can be extracted from the soil. By means of a powerful centrifugal machine Briggs has been able to obtain small quantities of such soil solutions when the amount originally in the soil was above a certain definite limit.[a] The volume of solution, however, actually obtainable with any reasonable amount of sample and time is so small as to preclude its use in any but special investigations, although its value for these special investigations and in giving us information as to the actual concentrations of soil solutions is of the greatest importance.

In view, therefore, of the practical impossibility of obtaining natural soil solutions for the purpose of this investigation, it was found necessary to prepare artificial aqueous solutions and to develop analytical methods adapted to the estimation of the small quantities of inorganic constituents dissolved in such solutions.

After a great deal of preliminary work the Bureau finally adopted the convention of taking 100 grams of the soil sample, stirring it vigorously for three minutes with 500 cc. distilled water, allowing it to stand twenty minutes for the coarser soil particles to subside, and decanting the supernatant solution containing more or less suspended clay and other solid matter. It was found by King, when working upon a series of soils of widely different physical characteristics, that by lengthening the time of agitation of the soil with water and then letting it stand through varying intervals from one-half minute to several hours the concentration of the resulting solutions increased, but that the procedure just cited led to results so near those obtained when longer intervals of time were employed that no material advantage could be thus obtained.[b]

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[a] This limit has been found to vary with each particular soil type and thus far has probably never been below that at which plants would fail to show a vigorous growth.

[b] In the solution of such difficultly soluble material as are the principal soil components the time element, as well as the state of subdivision of the material, probably largely influences the result. There is no sharp line between readily soluble and difficultly soluble material, but, on the contrary, in either case if the equilibrium of the solution be disturbed by the withdrawal of some of the dissolved salts, more of the material will go into solution. It has been frequently shown to be impossible to extract the soluble material from the soil completely, and probably it could not be done without an extremely large quantity of water acting for an almost infinite

After allowing the supernatant solution to stand for twenty minutes it is decanted from the residue of heavier soil particles and filtered by means of a Chamberland-Pasteur unglazed porcelain filter fitted to the forced-air device described by Briggs.[a] For this work the porcelain filters require careful preliminary treatment. They should be boiled for some time in two or more successive portions of distilled water and then cleansed by forcing through them considerable quantities of distilled water. When in use, and after a soil solution has been passed through a filter, it should be carefully washed by forcing distilled water through it, and in all cases the first runnings of 100 to 150 cc. should be discarded when filtering a solution for work.

To test the effect of these filters upon the solution a number of experiments have been made which show that they do not materially alter the composition of the solution. They are, of course, somewhat soluble in water, but how slight this solubility is the following experiments illustrate: Three filters, which had been previously prepared as described, were treated with distilled water, and the resistances, in ohms calculated to 60° F., of both waters and filtrates, were determined, with the following results:

Resistance, distilled water.	Resistance, filtrates.		
	I.	II.	III.
90,545	36,218	39,004	37,465

Another experiment was made by passing three successive portions of distilled water through one and the same filter, drying the filter between filtrations by forcing air through it. The resistances obtained are as given below:

Resistance, distilled water.	Resistance, filtrates.		
	I.	II.	III.
148,810	37,840	52,665	54,350

time, resulting in the complete solution of the entire mineral substance. Where extracts of soils are made by frequent short extractions or by longer digestions and decantations or filtrations, the soil will go slowly into solution, and will continue to do so although the rate of solution may become exceedingly slow. In this connection reference may be made to some of our own studies on the comparatively large amounts of gypsum present in irrigation waters in arid regions. Cameron found (Bul. No. 18, Division of Soils, U. S. Dept. Agr., p. 36 et seq., 1901) that where such waters were evaporated to dryness and taken up with a volume of water equal to that originally present, a large amount of gypsum did not go at once into solution, and it was necessary to allow this solution to stand, with frequent shakings, for periods varying from eight to twenty-two days before this gypsum was redissolved. The rapidity of this re-solution depends very largely upon the size of the individual crystals in which the gypsum was deposited from the original solution.

[a] Bul. No. 19, p. 31, Bureau of Soils, U. S. Dept. Agr., 1902.

From these figures it is evident that the filter is itself slightly soluble in water, but to so slight an extent as to have no appreciable effect upon the results of a chemical examination of the solution.

For the information of others, who may desire to employ the methods used in this investigation in their own work, a detailed description of the operations is given in an appendix. Briefly summarized, the methods are as follows:

The bicarbonates are determined by titrating the filtered aqueous extract of the soil with a dilute acid solution, using methyl orange as an indicator; the chlorides by titrating with a dilute solution of silver nitrate, using carefully prepared potassium chromate as an indicator; the sulphates photometrically, using a modification of a method proposed by Hinds and Jackson; the nitrates by developing the color resulting from the addition of phenol-disulphonic acid, making the solution slightly alkaline with ammonia, and then comparing photometrically with a standard solution of potassium nitrate similarly treated; the phosphoric acid by comparing the color produced by adding molybdic acid to a solution containing phosphates in the presence of nitric acid with the color produced in a standard solution of sodium phosphate treated in a similar manner; the silica by the use of the nitric acid and molybdate solution, after allowing the soil solution to stand at least one hour, reading against the phosphate standard and subtracting the previous reading for phosphate; the potassium from the color produced when an excess of potassium iodide is added to a solution of a platinic salt and photometrically compared with a standard similarly treated, and the calcium and magnesium by an adaptation of the well-known Clark soap method, modified by Winkler, Warthe, and others.

Of the mineral plant foods for whose determination the above methods have been devised there are but four which at the present time are considered in fertilizer practice, nor does there seem any reason to believe that the future will bring any change in this matter except possibly in special cases. These four constituents, calcium, potassium, phosphoric acid, and nitric acid, have generally been held to be the ones having the greatest practical significance for plant nutrition, and they are the ones which the demands of agriculture have brought into economic significance. It is therefore a cause of great satisfaction that, of the methods described above, those devised for these particular constituents are especially satisfactory.

In several series of solutions containing from 0.15 to 5 parts per million of potassium the variation of the results, as determined, from the calculated values, was in all cases less than one part per fifty million of solution. No such accuracy is attempted as a rule, but it is believed that as usually carried out by the men whom the Bureau has trained the determination is accurate to within one part in five million

of solution. The nitrate method is probably quite as accurate, and experience has led us to believe that the phosphate and calcium determinations are reliable to within a half to one part per million of solution. With these considerations in view it has seemed wiser to confine our argument to the data obtained from these four determinations, but it is only fair to say that the data for the other determinations, made from several hundred soil samples, bear out the conclusions advanced in this bulletin. We therefore present here only the results obtained for phosphoric acid, nitric acid, calcium, and potassium, and our field investigators now confine their work to these four, unless circumstances indicate the wisdom of making other determinations as well.

It should be remembered that the procedure just described does not tell us what concentration or exact composition the soil solution *in situ* has, although it would seem fair to assume that a close approximation could be made from it, nor does it tell us how much mineral matter is actually in solution in a soil; but it does give a close approximation to the amount that will go into solution when water and soil are brought together in the proportion of 1 to 5 by weight. The chief value of the procedure therefore is not so much in the information which it affords as to any one particular soil, but in the basis it furnishes for comparing various soils.

It must also be borne in mind that such a procedure as we have been describing can not, as other investigators have sometimes supposed, afford a criterion between soluble and nonsoluble salts in the soil, else the proportion of water to soil used, above a certain minimum, would be immaterial as far as the amounts which go into solution are concerned. This, as has been pointed out above, is theoretically erroneous, considering the chemical nature of the soil components, and has not been borne out by the experimental evidence. Consequently, the concentration of the soil solution is not simply the ratio of the amounts found to the percentage of moisture in the soil, but something of quite a different nature. With these considerations in mind, it has seemed best to compute the results on the basis of weight of dry soil, allowing for the water which might be in the sample as taken. The figures are given as parts per million merely for convenience.[a]

It should be pointed out that the methods used call for but little apparatus, and that of a comparatively simple character. Consequently we have been able to devise and assemble an equipment which may

[a] The computation of parts per million of soil from parts per million of solution is readily effected by the formula $S=\frac{R\,(500+H)}{100-H}$, where S= reading in terms of dry soil, R= reading in terms of soil solution, and H= grams of water in 100 grams of soil sample. This formula can be readily adapted to the scale reading for any of the determinations with proper allowances for the standards used, and of course when many determinations are to be made this will prove a great convenience.

readily be carried in a trunk of ordinary size. This equipment may be used wherever a room can be secured, and may be set up or packed within an hour. It is, therefore, of sufficiently mobile character to be adapted to field work, and our parties have been equipped to carry on their chemical work at the same time that they were making their field observations. Since it may be of interest for other investigators, we would say that in addition to the camera, Nessler cylinders, burettes, bottles for standards and reagents, and porcelain dishes incidentally mentioned, the equipment includes several dropping pipettes of varying capacities, a few bottles or flasks with appropriately marked capacities (250 cc. is the most generally convenient), a small balance, sensitive to a hundredth of a gram (a Springer torsion balance being found well adapted to this purpose), a small water oven with the top pierced so as to be used as a steam bath for drying samples, and a still for preparing distilled water, adapted to which purpose there are several convenient forms of apparatus designed for household use now on the market. An important item in such work—one which can not be more definitely described—is some personal ingenuity on the part of the operator.

With this, the apparatus detailed, and standard stock solutions, prepared at the main laboratory in Washington and forwarded when required, thoroughly satisfactory work has been accomplished by our field parties. Aside from saving time and avoiding the unsatisfactory features necessarily incident to work which is dependent for its direction upon correspondence, this equipment has permitted the examination of fresh samples of soil, frequently a matter of importance, since drying a sample affects the nitrate content of the soil and sometimes other constituents, besides precluding satisfactory data regarding water content. The adaptation of the methods just outlined to the analysis of a soil extract has been brought to such a state that it is now possible for one to start with a soil sample, prepare the extract, and report the analysis within a period of six hours, determining all the above-described constituents, and a field party of two men can readily report 40 analyses per week, besides attending to the many other details of their work.

STATEMENT OF RESULTS.

In the reports of the soil surveys it had been pointed out that some of the types of soils producing satisfactory yields of early truck and general farm corps in the Salem area, New Jersey, gave very small returns in southern Maryland, and that the Cecil clay of Harford County, Md., was much more productive than the same soil in the Statesville area of North Carolina. It was admitted that the methods of cultivation varied considerably in these several localities and it was significant that in the Statesville area a few farmers obtain nearly

the same yields of wheat, corn, and grass as are obtained upon the corresponding soil in Harford County, Md. But while the effect of cultivation was recognized by the Bureau as of paramount importance in influencing the yield, and while the texture of the soils, it was believed, had much to do with the yield and character of the crops grown even in the Salem area, where the cultivation is most intelligently carried out, it had always been thought that the difference in yield would be found to be associated with, if not directly determined by, the chemical characteristics of the soils.

It was to investigate this point and to establish, by means of the newly devised methods, the relations between the chemical characteristics of the soil and crop yields that Messrs. Taylor and Mooney were detached from the soil survey, assistants assigned to them and the parties furnished with portable chemical outfits, and sent into the areas above referred to. They spent most of the season in the field, making a large number of analyses by the methods already described, but with a result, as will be seen, somewhat different from that expected.

The soils particularly studied were the Sassafras loam in the Salem area, where this soil is very productive for general farm crops and highly valued for dairying, and the same soil in St. Mary County, Md., where it has only a fair agricultural value, the difference in price of the land ranging from about $100 an acre in the former locality, to $15 or $20 in the latter; the Norfolk sand, which has a high value for early truck crops in the Salem area, as well as for wheat in the low-lying, moist forelands, and is hardly utilized in St. Mary County; the Windsor sand, which has little value in either area, being a leachy, generally unproductive soil, made up as it is of coarse sand and fine gravel, and the Leonardtown loam, which does not occur in the Salem area, is found over a wide extent in St. Mary County, and is a soil that it would seem from former studies[a] should be, under proper cultivation and management, nearly as productive as the limestone soils of Pennsylvania, although under prevailing methods it has but little value and sells for $3 to $15 an acre.

In the Harford County area the Cecil clay gives yields of 25 or 30 bushels of wheat per acre, and through intelligent cultivation has become covered with a good loamy surface soil, while in the Statesville area the surface soil is not in this same loamy condition, and wheat yields from 5 to 8 bushels an acre, except upon a few farms where more thorough methods of cultivation have been practiced. In the Statesville area the Cecil sandy loam was also examined.

The tables following show the results obtained in these several areas. The figures from New Jersey and Maryland represent all the determinations made during the growing period of a wheat crop; those

[a] U. S. Dept. Agr., Field Operations Div. of Soils, 1900, pp. 33, 128.

from Statesville and from Harford county represent only a part of the determinations made in those areas. The remaining determinations lead to the same conclusions, but to give them would unnecessarily multiply the data. Where the condition of the crop is given in the table it must be understood to refer to the general condition, taking into consideration the crop value of that particular soil. Thus, where on the Windsor sand, for instance, the crop is stated to be in good condition, it means that the yield indicated would be good for a soil of this type, though not good for another type of greater natural productivity, for example, the Sassafras loam or the Cecil clay.

It will be seen from the following tables that there is no apparent relation between the dissolved salt of the soils, as determined by the methods outlined above and the yield of crops, and that there are no constant differences between the different types of soil, although these types differ widely in their agricultural and crop values.

Water-soluble constituents of the Windsor sand.

Date.	Area.	Crop.	Condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
April 10	Salem, N. J.	Clover	Good	0–12	12.10	10.26	1.43	7.58	27.36
Do	do	Onions	do	0–12	10.30	12.88	5.32	10.08	25.76
April 16	do	Clover	do	0–12	12.50	8.55	1.20	8.95	21.66
				12–24	10.00	6.72	.56	7.50	Lost.
May 21	St. Marys, Md	Corn	do	0–12	7.60	4.40	16.94	17.27	38.50
				12–24	10.10	6.16	5.71	2.52	27.44
May 23	do	do	do	0–12	4.60	2.65	4.66	4.77	22.26
				12–24	4.60	4.24	2.60	5.93	24.00
May 26	do	Tobacco fertilized.	do	0–12	8.10	6.60	7.70	9.90	25.74
				12–24	10.40	3.36	2.57	7.50	23.30
May 30	do	do	do	0–12	8.90	7.42	26.62	22.16	39.60
				12–24	9.30	6.87	6.27	9.90	34.10
March 24	Salem, N. J.	Clover	Medium	0–12	9.90	3.36	1.51	Tr.	19.20
				12–24	9.40	6.16	1.80	2.52	18.36
				24–36	10.00	5.60	1.12	Tr.	17.24
Do	do	do	do	0–12	10.10	5.00	2.70	3.00	19.00
				12–24	9.50	7.70	1.10	7.86	13.86
				24–36	11.80	4.56	1.14	7.63	18.70
April 10	do	Wheat	do	0–12	7.50	6.81	2.07	8.56	19.62
				12–24	6.40	10.53	1.35	10.80	Lost.
April 16	do	Sweet potatoes	do	0–12	9.50	6.38	1.22	3.89	20.88
				12–24	10.50	5.60	2.02	8.79	Lost.
April 10	do	Corn stubble	Poor	0–12	14.20	8.48	2.11	13.10	14.04
				12–24	12.20	6.84	1.82	11.40	Lost.
April 27	St. Marys, Md	do	do	0–12	7.60	4.90	9.80	6.10	10.90
				12–24	8.30	4.13	13.64	3.71	11.88
May 21	do	Fallow	do	0–12	1.90	7.65	6.12	5.71	25.00
				12–24	3.80	4.68	7.28	6.97	32.24
May 22	do	do	do	0–12	4.40	4.77	5.51	2.39	30.74
				12–24	6.40	4.32	4.54	2.43	28.62
May 26	do	Tobacco unfertilized.	do	0–12	9.00	3.85	4.90	8.63	20.90
				12–24	9.70	3.92	1.80	11.20	21.00
May 21	do	Tobacco just fertilized with bone and potassium.	do	0–12	4.30	9.01	22.68	47.50	46.11
Do	do	Tobacco not fertilized.	do	0–12	3.00	6.76	15.81	9.36	30.16

Water-soluble constituents of the Norfolk sand.

Date.	Area.	Crop.	Condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
March 10	Salem, N. J.	Wheat	Good	0–12	13.20	11.60	2.55	5.22	11.83
				12–24	11.50	7.40	1.60	5.13	16.18
March 31	do	Tomatoes	do	0–12	10.70	2.80	1.34	10.02	26.43
				12–24	10.90	3.92	1.57	8.80	31.14
April 3	do	Clover	do	0–12	14.80	16.52	2.48	11.92	24.19
				12–24	14.70	14.75	1.42	10.56	24.78
May 23	St. Marys, Md	Wheat	do	0–12	13.50	6.96	4.87	10.44	20.18
				12–24	17.10	5.70	2.76	13.44	19.00
May 27	do	do	do	0–12	10.10	5.04	1.85	6.27	19.50
				12–24	16.30	4.80	1.50	13.44	19.68
				24–36	21.20	3.78	1.51	8.44	25.70
				36–48	22.10	4.72	2.00	5.57	26.20
May 28	do	Pease	do	0–24	11.70	6.72	10.08	7.50	30.46
May 30	do	Rye	do	0–12	11.20	6.84	2.16	12.77	21.00
				12–24	7.80	8.25	1.21	11.11	26.40
June 8	Salem, N. J.	Corn	do	1–24	11.20	4.56	14.25	16.53	13.68
Do	do	Wheat	do	1–24	4.30	3.64	4.05	14.00	13.00
June 11	do	Sweet potatoes	do	1–24	9.20	8.80	22.44	27.11	25.74
June 13	do	Wheat	do	1–24	4.60	5.03	2.12	13.00	17.30
June 16	do	Corn	do	1–24	8.00	3.30	10.34	13.53	19.36
June 19	do	Wheat	do	1–24	9.60	2.24	2.80	13.77	23.96
Do	do	Sweet potatoes	do	1–24	7.60	4.40	1.10	9.90	21.56
April 24	St. Marys, Md.	Corn stubble	Medium	0–12	15.90	8.26	15.34	9.38	16.05
				12–24	18.40	7.93	12.93	10.92	17.08
May 27	do	Clover	do	0–12	6.80	7.56	2.05	8.48	22.68
				12–24	10.60	2.80	1.23	13.77	23.30
Do	do	Wheat	do	0–12	8.10	8.15	2.64	8.63	19.58
				12–24	8.60	4.40	1.43	11.11	17.60
May 29	do	Corn	do	0–12	14.70	5.00	9.44	5.31	24.17
				12–24	12.70	6.96	2.32	5.22	22.50
March 10	Salem, N. J.	Clover	do	0–12	15.50	7.67	3.77	3.18	17.90
				12–24	15.20	4.13	3.54	2.65	11.80
March 14	do	Wheat	do	0–12	9.65	8.40	1.34	2.52	17.00
				12–24	10.30	7.28	.67	6.27	18.80
				24–36	13.40	7.00	1.85	5.80	15.00
Do	do	Clover	do	0–12	12.70	11.60	2.32	5.22	16.50
				12–24	12.90	9.28	1.62	Tr.	23.20
				24–36	17.50	2.40	2.40	2.70	33.60
March 20	do	do	do	0–12	11.70	5.70	1.50	3.80	20.00
				12–24	9.55	3.92	1.40	3.00	18.36
				24–36	14.30	5.80	1.56	11.70	22.50
Do	do	Wheat	do	0–12	8.65	5.50	1.60	9.84	21.34
				12–24	7.30	6.50	1.40	5.40	20.00
				24–36	8.25	5.50	1.50	6.90	21.50
March 26	do	Clover	do	0–12	19.00	7.93	1.46	4.63	23.20
				12–24	13.80	3.50	1.85	4.70	20.40
				24–36	16.90	4.80	4.32	2.70	14.40
Do	do	Wheat	do	0–12	11.70	5.70	1.60	5.13	13.70
				12–24	13.10	7.00	1.74	5.22	19.00
				24–36	17.60	8.40	1.92	7.00	19.20

Water-soluble constituents of the Norfolk sand—Continued.

Date.	Area.	Crop.	Condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
March 31	Salem, N. J	Wheat	Medium	0–12	18.10	5.49	.85	9.58	44.90
				12–24	20.60	2.48	.87	11.10	40.67
Do	do	Corn stubble	do	0–12	12.90	5.80	1.39	7.77	40.83
				12–24	14.00	4.64	1.51	11.72	43.62
April 3	do	do	do	0–12	10.40	10.64	3.58	11.31	22.40
				12–24	16.10	11.40	3.48	8.04	26.88
April 9	do	Tomatoes	do	0–12	13.20	13.92	1.74	46.86	30.16
				12–24	12.10	3.99	1.25	7.58	Lost.
Do	do	Sweet potatoes	do	0–12	9.60	5.60	1.12	7.45	22.40
				12–24	9.70	6.72	1.00	7.45	Lost.
April 16	do	Peppers	do	0–12	11.00	8.48	1.58	12.66	11.64
				12–24	10.50	6.16	1.51	10.02	Lost.
Do	do	Tomatoes	do	0–12	10.70	6.72	1.34	8.79	14.90
				12–24	16.60	6.60	2.88	8.04	Lost.
June 6	do	Clover	do	0–12	2.30	8.16	2.04	11.42	17.34
				12–24	2.40	6.63	1.22	8.67	16.32
June 11	do	Rye	do	1–24	9.70	3.92	5.15	23.85	14.11
June 16	do	Corn	do	1–24	12.50	3.42	1.70	6.53	19.15
Do	do	Tomatoes	do	1–24	8.50	4.40	7.26	12.32	20.90
March 24	do	Rye	Poor	0–12	13.80	4.64	2.09	4.70	26.00
				12–24	12.05	2.85	1.60	3.82	36.50
April 3	do	Wheat	do	0–12	12.05	11.40	2.28	5.13	31.92
				12–24	12.00	10.26	2.05	2.56	21.66
April 4	do	Barren	do	0–12	11.40	8.55	1.14	2.56	23.94
				12–24	9.30	7.22	1.33	6.22	31.64
Do	do	Corn stubble	do	0–12	12.90	12.18	2.09	5.22	31.90
				12–24	10.90	12.43	1.13	10.17	28.25
April 24	St. Marys, Md	do	do	0–12	10.10	6.16	12.32	7.50	12.54
				12–24	12.50	4.56	14.82	6.38	14.14
April 27	do	do	do	0–12	10.10	3.92	10.75	3.75	14.56
				12–24	12.20	1.71	10.03	2.57	15.96
May 1	do	Scrub forest	do	0–12	9.20	11.10	6.66	7.44	23.87
				12–24	8.20	6.05	4.62	3.70	26.40
May 15	do	Fallow	do	0–12	4.00	5.46	22.36	11.65	30.78
				12–24	6.40	3.24	23.76	24.19	27.54
May 23	do	Wheat	do	0–12	10.70	5.04	3.02	8.80	26.00
				12–24	15.20	5.31	3.18	10.62	24.07
May 27	do	do	do	0–12	11.90	5.04	1.56	7.50	21.05
				12–24	14.30	4.42	1.18	10.62	27.14
Do	do	do	do	0–12	7.70	5.50	2.09	7.37	21.12
				12–24	11.00	5.60	2.13	12.54	26.88
May 28	do	Fallow	do	0–24	9.00	4.67	3.08	4.95	21.12
June 6	Salem, N. J	Corn	do	0–12	4.80	6.36	3.50	10.60	19.30
				12–24	7.30	5.94	1.73	10.80	17.50
June 11	do	Sweet potatoes	do	1–24	9.20	3.85	2.00	17.27	14.30
June 13	do	Corn	do	1–24	6.40	2.60	4.32	10.80	20.30
June 16	do	Grass	do	1–24	8.60	3.85	1.32	15.95	15.62
Do	do	Wheat	do	1–24	9.30	4.48	1.80	28.84	20.38

Water-soluble constituents of the Sassafras loam.

Date.	Area.	Crop.	Condition.	Depth of sample, in inches.	Percent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
March 17	Salem, N. J.	Wheat	Good	0–12	22.05	8.20	6.80	5.67	10.46
				12–24	18.15	7.80	5.52	14.75	13.68
Do	do	do	do	0–12	18.35	9.76	5.73	15.00	Lost.
				12–24	18.10	8.54	2.68	24.50	24.64
March 24	do	do	do	0–12	24.70	13.65	2.60	11.70	30.16
				12–24	22.30	7.56	1.90	11.34	37.80
March 26	do	do	do	0–12	23.40	3.84	2.56	15.74	16.38
				12–24	23.90	11.52	3.71	15.74	20.48
				24–36	22.40	8.19	2.52	2.84	20.66
April 2	do	do	do	0–12	25.60	7.80	2.21	16.00	30.16
				12–24	24.40	7.80	2.21	17.50	46.80
				24–36	21.60	7.56	2.02	11.28	37.80
April 24	St. Marys, Md	do	do	0–12	21.40	6.93	12.85	10.00	20.16
				12–24	19.80	8.68	9.42	6.94	13.40
May 1	do	Clover	do	0–12	17.40	8.40	10.56	12.12	21.60
				12–24	22.20	7.56	11.34	9.90	30.24
May 14	do	Wheat	do	0–12	11.60	5.13	22.80	17.90	27.93
				12–24	13.90	4.06	16.24	16.82	31.32
June 5	Salem, N. J.	Corn	do	0–12	15.20	8.85	16.52	51.77	26.43
				12–24	19.80	5.89	9.55	27.78	26.78
Do	do	Wheat	do	0–12	5.20	14.31	3.18	51.04	23.32
				12–24	8.00	14.85	2.53	55.44	31.90
June 8	do	do	do	1–24	10.60	2.24	1.80	20.00	13.44
Do	do	Clover	do	1–24	8.80	3.30	1.65	16.00	13.00
June 11	do	Wheat	do	1–24	15.50	5.90	2.30	26.43	13.92
Do	do	do	do	1–24	10.60	7.28	2.52	62.72	16.57
June 13	do	do	do	1–24	8.20	6.48	1.62	19.33	21.60
Do	do	Clover	do	1–24	6.20	7.02	3.02	21.76	24.20
June 16	do	Corn	do	1–24	20.30	4.96	24.80	25.00	21.57
Do	do	Wheat	do	1–24	15.00	5.00	1.53	21.12	18.88
June 19	do	Corn	do	1–24	14.80	2.95	15.93	21.12	36.58
Do	do	Pasture	do	1–24	10.60	4.48	1.34	10.08	28.24
March 10	do	Grass	Medium	0–12	25.00	13.00	2.34	27.70	18.20
				12–24	23.80	7.04	1.53	25.80	12.80
				24–36	19.90	16.12	1.00	8.30	15.00
Do	do	Wheat	do	0–12	23.25	18.56	3.58	10.05	7.94
				12–24	21.60	11.16	4.71	9.73	13.90
March 14	do	do	do	0–12	22.30	17.64	14.36	7.62	18.14
				12–24	20.20	15.50	7.20	12.00	21.30
				24–36	20.30	18.00	6.94	17.23	16.36
Do	do	Grass	do	0–12	25.80	21.45	9.36	11.70	21.32
				12–24	23.10	7.56	3.52	12.16	15.12
				24–36	21.80	8.82	2.77	15.16	21.16
March 20	do	Wheat	do	0–12	19.30	7.44	4.71	9.73	21.32
				12–24	18.60	4.27	5.61	10.90	21.00
				24–36	12.60	4.64	3.48	11.70	20.85
Do	do	Clover	do	0–12	20.80	4.96	2.08	15.25	31.75
				12–24	20.20	4.96	1.00	15.25	27.30
				24–36	18.60	7.32	.50	12.32	35.60

Water-soluble constituents of the Sassafras loam—Continued.

Date.	Area.	Crop.	Condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
March 26	Salem, N. J.	Clover	Medium	0–12	26.80	8.58	2.77	31.02	20.33
				12–24	22.90	8.32	1.54	20.16	18.18
				24–36	22.50	3.78	1.00	14.11	19.70
March 31	do	Sod plowed	do	0–12	25.20	3.90	6.11	29.12	36.14
				12–24	24.50	7.80	1.95	29.12	29.12
Do	do	Grass	do	0–12	23.00	10.88	2.69	22.90	43.00
				12–24	21.60	7.56	1.51	19.78	34.27
April 2	do	do	do	0–12	24.80	7.80	3.25	16.00	40.80
				12–24	24.00	5.70	1.28	21.50	38.40
				24–36	21.40	3.15	1.00	11.28	25.20
June 6	do	Clover	do	0–12	8.10	8.25	1.43	15.95	17.27
				12–24	12.70	8.99	1.16	18.21	20.00
June 8	do	Corn	do	1–24	17.10	3.60	11.04	25.56	15.36
June 13	do	do	do	1–24	25.60	6.50	18.60	24.76	26.52
June 16	do	do	do	1–24	22.40	3.78	25.70	25.40	24.70
Do	do	do	do	1–24	22.50	4.41	15.50	24.00	22.68
April 29	St. Marys, Md	Wheat	do	0–12	18.10	4.27	13.42	16.40	25.13
				12–24	20.20	4.34	22.82	19.47	25.54
May 1	do	Sod plowed	do	0–12	16.10	6.30	38.40	14.76	21.00
				12–24	18.90	7.32	30.26	8.17	26.84
March 31	do	Wheat	Poor	0–12	22.80	6.40	4.61	54.46	20.28
				12–24	21.20	6.30	3.40	40.82	39.56
April 29	do	Pasture	do	0–12	13.20	4.06	14.50	7.77	29.00
				12–24	14.80	4.13	11.56	13.22	30.21
May 14	do	Wheat	do	0–12	11.20	11.40	20.52	15.40	26.22
				12–24	15.30	4.72	15.60	10.62	33.04
May 15	do	do	do	0–12	12.40	3.42	23.37	19.15	31.00
				12–24	19.60	5.58	35.96	24.80	36.00
June 8	Salem, N. J.	do	do	1–24	10.60	3.36	1.57	18.81	13.21
June 11	do	do	do	1–24	14.90	4.72	2.47	25.13	16.28
June 16	do	do	do	1–24	16.90	4.20	1.32	16.20	19.20

Water-soluble constituents of the Leonardtown loam.

Date.	Area.	Crop.	Condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
April 23	St. Marys, Md	Grass	Good	0–12	16.00	11.40	1.68	18.84	24.96
				12–24	16.10	6.60	4.44	29.58	26.16
April 27	do	Wheat	do	0–12	21.80	4.73	15.62	10.00	12.10
				12–24	21.30	4.41	10.33	7.06	10.08
April 29	do	do	do	0–12	22.20	7.56	13.23	15.50	51.66
				12–24	21.80	3.78	7.81	11.34	37.80
May 1	do	do	do	0–12	22.40	7.25	16.88	14.11	23.31
				12–24	21.80	6.93	16.13	8.44	29.61
Do	do	do	do	0–12	17.00	5.40	15.84	16.20	25.20
				12–24	21.00	5.00	17.25	7.00	19.38
May 4	do	Clover	do	0–12	14.20	5.56	14.51	13.10	27.50
				12–24	16.00	15.17	8.09	5.39	26.18
May 8	do	Corn	do	0–12	18.20	9.46	14.60	12.20	29.28
				12–24	18.90	10.37	9.03	6.83	25.63
May 9	do	Wheat	do	0–12	15.00	12.70	11.10	34.22	28.32
				12–24	15.90	9.44	12.50	17.11	26.00
May 15	do	do	do	0–12	14.20	2.90	13.22	14.33	24.36
				12–24	19.90	3.72	10.91	12.52	24.80
Do	do	Woods	do	0–12	12.70	4.64	23.20	15.66	27.84
				12–24	13.80	4.06	22.04	14.33	30.16
May 18	do	Corn	do	0–12	18.20	3.36	42.09	24.40	37.82
				12–24	18.80	6.10	21.96	18.90	28.06
Aug. 8	do	Corn	do	0–24	17.50	7.12	52.50	29.52	17.52
Aug. 14	do	Wheat	do	0–24	15.00	6.13	Tr.	10.62	13.04
Aug. 15	do	do	do	0–24	15.70	4.91	3.19	2.66	16.70
Do	do	do	do	0–24	16.40	7.52	Tr.	14.76	14.52
April 23	do	Wheat	Medium	0–12	21.10	12.17	8.94	22.55	17.64
				12–24	22.20	13.23	10.08	22.55	20.16
May 4	do	Cowpeas	do	0–12	17.40	7.20	13.20	9.42	25.80
				12–24	20.30	7.75	16.62	8.31	26.04
May 30	do	Wheat	do	0–12	16.70	7.50	1.68	14.76	27.00
				12–24	14.30	8.70	2.20	9.10	20.88
Aug. 15	do	Corn	do	0–24	18.30	5.44	Tr.	17.75	12.20
Do	do	Tobacco	do	0–24	20.40	6.04	8.25	16.68	16.55
April 23	do	Pasture	Poor	0–12	23.90	14.08	3.84	14.34	20.48
				.....	26.10	16.50	6.86	8.84	21.45
April 24	do	Barren	do	0–12	17.00	6.00	9.60	13.44	13.92
				12–24	17.00	4.80	5.76	9.54	18.48
April 27	do	Wheat	do	0–12	24.80	5.85	15.34	11.64	15.60
				12–24	23.80	3.84	16.90	10.18	14.60
April 29	do	do	do	0–12	14.00	5.80	8.50	16.82	33.64
				12–24	16.60	6.00	10.08	10.80	33.60
May 1	do	do	do	0–12	19.50	5.27	17.86	12.52	12.40
				12–24	24.30	9.68	22.96	10.32	18.06
May 8	do	Fallow	do	0–12	18.20	9.15	15.37	13.66	19.52
				12–24	18.40	12.81	17.57	5.50	26.84
Do	do	Wild grass	do	0–12	22.70	8.26	18.80	10.60	25.40
				12–24	21.50	10.40	10.33	4.22	26.46
May 14	do	Wheat	do	0–12	14.70	4.72	15.34	7.90	35.40
				12–24	19.90	4.34	11.16	4.15	30.38

Water-soluble constituents of the Leonardtown loam—Continued.

Date.	Area.	Crop.	Condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
						Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
May 18	St. Marys, Md.	Corn	Poor	0–12	18.30	3.36	31.72	31.42	29.38
				12–24	23.40	8.00	24.96	15.81	32.64
May 23	do	do	do	0–12	16.60	5.40	7.92	12.00	21.60
				12–24	17.40	6.00	3.60	8.04	21.60
Do	do	Wheat	do	0–12	7.80	4.40	1.65	7.37	21.56
				12–24	14.90	3.60	2.40	10.80	22.80
May 30	do	Rye	do	0–12	18.20	6.10	1.83	12.32	33.55
				12–24	15.70	6.50	1.06	5.31	27.14
Aug. 8	do	Corn	do	0–24	19.90	8.60	62.00	24.99	20.40
Aug. 14	do	Wheat	do	0–24	16.00	4.48	2.42	3.95	15.75
Aug. 15	do	do	do	0–24	19.50	6.45	Tr.	4.15	13.45
Do	do	Corn	do	0–24	21.60	7.48	3.40	15.50	13.42

Water-soluble constituents of the Cecil sandy loam.

Date.	Area.	Crop and condition.	Depth of sample in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
					Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
March 19	Statesville, N. C.	Cotton field, very poor	0–12	26.2	3.72	4.96	.....	13.66
			12–24	28.7	4.06	4.88	.....	22.23
March 26	do	Wheat stubble, poor	0–12	21.2	2.51	4.64	.....	16.42
			12–24	36.4	8.62	5.68	.....	12.78
Do	do	Wheat, fair, fertilized	0–12	11.6	2.28	3.41	.....	17.10
			12–24	20.5	1.24	11.69	.....	14.43
			24–36	28.5	1.34	16.50	.....	13.95
Do	do	Pasture, just plowed, poor	0–12	24.8	.....	7.33	.....	8.28
			12–24	33.0	.....	13.76	.....	12.84
March 28	do	Old field pine, poor	0–12	19.5	11.09	1.23	.....	8.63
			12–24	20.5	9.97	1.05	.....	7.47
March 30	do	Corn last year, fallow, poor.	0–12	23.2	5.75	17.89	.....	15.33
			12–24	34.9	12.34	3.15	.....	10.49
			24–36	34.9	9.92	4.58	.....	10.21
Do	do	Duplicate solutions made from preceding sample.	0–12	23.2	7.03	6.00	.....	9.43
			12–24	34.9	6.38	23.39	.....	9.64
			24–36	34.9	7.04	9.92	.....	10.91
April 8	do	Old pasture after 2 days heavy rain.	0–12	20.0	5.58	5.46	.....	22.82
			12–24	28.4	3.35	28.41	.....	25.99
April 9	do	Wheat, 20 bushels	0–12	14.8	0.59	2.82	.....	20.50
			12–24	18.8	2.44	5.12	.....	19.09
Do	do	Fallow after oats	0–12	17.9	4.26	2.68	.....	17.75
			12–24	35.5	4.99	3.42	.....	21.10
Do	do	Cotton last year; ¾ bale; now fallow, sample from row.	0–12	19.3	3.70	1.48	.....	21.19
			12–24	21.6	8.82	4.03	.....	.....
Do	do	Sample taken between rows. Same field as above; 2 feet below.	0–12	19.3	4.31	6.78	.....	24.33
			12–24	24.5	11.0	24.85	.....	26.14

Water-soluble constituents of the Cecil sandy loam—Continued.

Date.	Area.	Crop and condition.	Depth of sample, in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
					Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
April 15	Statesville, N. C.	Wheat, 15 bushels	0–24	24.7	7.78	8.55	11.66	31.62
Do	do	Clover after wheat; fair stand.	0–24	21.8	6.94	2.52	14.13	34.70
April 17	do	Old garden in sod	0–24	23.3	10.24	7.68	100.35	72.70
Do	do	Rye sown in cotton field; cotton over ½ bale. Rye looks well.	0–24	16.5	8.39	6.47	26.84	66.08
Do	do		0–24	17.6	13.33	3.64	18.97	42.16
Do	do	Rye, next field to above; very poor.	0–24	25.6	7.19	5.23	17.59	47.08
Do	do	Clover, excellent stand, rank growth.	0–24	16.0	11.92	.....	16.03	48.63
Do	do	Clover, good; wheat, 25, has made 39 bushels.	0–24	23.4	12.80	3.84	14.34	48.12
May 18	do	Wheat, 10 bushels	0–12	5.5	.....	1.91	21.36	42.40
Do	do	Rye, 8 to 10 bushels	0–12	8.8	.....	2.21	14.82	47.78
Do	do	Rye, 4 to 6 bushels	0–12	7.4	.....	0.44	19.48	50.48
Do	do	Wheat, 15 to 20 bushels	0–12	13.2	.....	0.92	20.69	32.37
Do	do	Wheat, 2 bushels	0–12	7.8	.....	0.66	19.58	34.13
May 19	do	Wheat, 3 to 5 bushels	0–12	19.8	.....	0.50	11.08	37.62
Do	do	Wheat, 10 to 12 bushels	0–12	5.6	.....	1.28	21.52	34.18
May 20	do	do	0–12	4.4	6.31	1.47	25.93	32.40
Do	do	Wheat, 8 to 10 bushels	0–12	4.0	6.29	1.26	21.12	37.73
Do	do	Just planted to corn; fallow after peas; poor; 2 to 5 bushels wheat.	0–12	10.7	12.97	2.03	15.17	39.71
Do	do	Spring oats; will make 6 to 12 bushels wheat.	0–12	10.1	7.84	1.57	25.09	27.78
May 21	do	Wheat, 12 to 15 bushels	0–12	8.0	10.96	2.19	19.62	47.35
			12–24	22.4	11.41	11.41	22.70	38.55
May 22	do	Wheat, 6 to 10 bushels	0–12	5.8	9.63	Tr.	19.15	28.25
Aug. 8	do	Cowpeas and corn after wheat. Good stand. Plowed deep. Some fertilizer and manure. Land that has been improved. Crop value about three times the following sample.	0–12	14.7	19.99	3.00	.....	39.40
			12–24	19.8	16.07	19.70	.....	37.50
Do	do	Cowpeas after wheat. Next field to above. Very poor and poorly farmed.	0–12	6.8	27.59	1.70	.....	53.50
			12–24	18.4	20.74	2.40	.....	43.90
Aug. 10	do	Wheat stubble. Fair land. Has been manured and well plowed.	0–12	3.9	2.62	9.40	.....	35.00
			12–24	9.5	8.36	2.60	.....	16.90
Do	do	Old winter oat stubble. No crop this year. Growth of weeds. Next field to above on same farm. No manure and has not been handled so well as preceding.	0–12	14.0	9.90	6.30	.....	20.70
			12–24	22.5	10.80	4.50	.....	16.80

Water-soluble constituents of the Cecil clay.

Date.	Area.	Crop and condition.	Depth of sample, in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
					Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
March 17	Statesville, N. C.	Winter oats; poor land after heavy rains.	0–12	19.5	3.70	13.24	.....	6.16
			12–24	23.4	12.80	12.93	.....	10.88
Do	do	Rye, good stand; plowed deep; no fertilizer.	0–12	17.9	4.86	5.03	.....	6.37
			12–24	25.3	5.22	5.67	.....	7.17
Do	do	Rye, heavier than above; old field just cleared.	0–12	23.8	8.96	5.12	.....	7.04
			12–24	29.5	6.70	12.06	.....	6.70
Do	do	(*A*) Clover, good stand; top dressed manure; good for 25 bushels wheat.	0–12	24.7	15.55	9.07	.....	5.18
			12–24	35.1	18.46	11.36	.....	7.10
			24–36	30.7	21.89	10.94	.....	9.58
Do	do	Same field as above	0–12	19.6	7.30	11.10	.....	4.93
			12–24	20.9	13.25	10.00	.....	6.25
Do	do	do	0–12	20.2	9.94	23.60	.....	4.97
			12–24	21.4	12.50	28.75	.....	6.50
March 20	do	Corn; good land, but poorly treated.	0–12	23.4	8.96	4.36	.....	28.16
			12–24	33.9	38.66	4.36	.....	28.12
Do	do	Cotton field; sown to rye; good yield cotton.	0–12	23.4	17.92	7.68	.....	18.68
			12–24	33.0	40.60	30.05	.....	28.00
March 23	do	Same field as (*A*) after 2½ days of heavy rain.	0–12	25.8	6.55	9.10	.....	16.24
			12–24	30.4	8.17	7.69	.....	13.34
			24–36	26.2	3.95	4.01	.....	11.58
Do	do	Same field as above	0–12	23.9	8.70	12.07	.....	17.21
			12–24	29.9	12.22	3.38	.....	13.04
Do	do	Wheat, very good; 20 to 25 bushels.	0–12	20.5	8.08	5.60	.....	5.35
			12–24	34.2	11.98	34.12	.....	7.89
			24–36	31.5	13.78	3.44	.....	7.44
April 3	do	Fallow, thrown out of cultivation.	0–12	18.3	13.42	1.46	.....	12.20
			12–24	25.3	5.42	1.46	.....	15.12
Do	do	Old fence row to compare with the above.	0–12	20.5	12.46	2.99	.....	17.44
			12–24	23.3	12.16	4.35	.....	21.24
April 6	do	Wheat, 15 to 20 bushels; been improved.	0–12	25.8	7.19	4.97	.....	28.25
			12–24	31.2	6.87	3.30	.....	20.20
Do	do	Fallow, just planted to corn; poor; wheat, 5 to 10 bushels.	0–12	23.9	5.79	15.95	.....	23.66
			12–24	31.2	8.40	15.68	.....	27.72
April 11	do	Same field as (*A*)	0–12	19.0	3.70	3.94	.....	27.10
			12–24	19.1	4.04	2.42	.....	23.08
Do	do	Wheat; adjoining (*A*); good yield in prospect.	0–12	18.3	9.16	2.93	.....	19.55
			12–24	24.7	7.78	2.07	.....	18.14
April 14	do	North Carolina experiment farm; fallow, for grass-plot.	0–12	20.2	8.69	3.48	11.12	26.33
			12–24	27.1	11.92	16.95	11.65	39.69
			24–36	16.3	7.77	22.48	10.70	24.88
Do	do	Same field as above	0–12	27.4	9.30	6.90	11.88	27.81
			12–24	21.2	10.03	7.52	11.54	31.85
			24–36	30.7	8.21	26.81	11.24	31.19
April 15	do	Poor land; corn; thrown out.	0–24	25.6	13.08	3.92	14.65	30.87
Do	do	Wheat, fair	0–24	27.4	10.62	5.05	11.95	32.13
Do	do	do	0–24	22.2	6.93	3.04	11.39	31.65
Do	do		0–24	28.5	12.10	3.23	18.08	37.36
April 17	do	Wheat, 25 bushels	0–24	30.4	15.00	5.73	24.42	62.20

Water-soluble constituents of the Cecil clay—Continued.

Date.	Area.	Crop and condition.	Depth of sample, in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
					Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
April 17	Statesville, N. C..	Wheat, three years in succession; with cowpeas; wheat, 25 to 30 bushels.	0–24	35.7	13.57	.....	31.99	60.55
Do...	.....do.....	Fallow; cotton last year; sample (in row); considered very poor; wheat, 3 to 5 bushels.	0–24	30.9	13.02	4.66	21.44	60.28
May 9	Harford Co., Md..	Plowed field; wheat, 30 to 35 bushels.	0–24	23.4	8.16	5.53	56.37	28.64
Do...	.....do.....	Wheat, 30 to 35 bushels.....	0–24	20.5	3.73	12.94	55.73	45.78
May 11	.....do.....	Wheat, 30 bushels; field had good treatment; last year in corn; top dressed, manure and lime; 500 pounds fertilizer.	0–24	23.0	5.10	1.53	102.85	34.71
Do...	.....do.....	Wheat, 30 to 45 bushels; 25 to 30 bushels always expected; highly improved; manured; limed, and 500 pounds fertilizer.	0–24	19.5	8.65	1.98	66.44	25.71
Do...	.....do.....	Wheat, 25 to 30 bushels; improved farm.	0–24	18.9	9.20	1.96	54.92	23.54
Do...	.....do.....	Wheat, 25 to 40 bushels; improved farm.	0–24	21.1	10.76	1.52	56.72	28.36
Do...	.....do.....	Wheat, poor.....	.....	27.1	7.39	3.18	71.17	22.24
Do...	.....do.....	.....do.....	.....	19.3	6.16	3.20	99.30	20.70
Do...	.....do.....	.....do.....	.....	16.3	6.57	2.63	61.49	35.34
Do...	.....do.....	.....do.....	.....	16.3	9.45	1.91	58.80	23.40
Do...	.....do.....	.....do.....	.....	19.9	9.92	0.74	49.97	34.72
Do...	.....do.....	.....do.....	.....	20.5	9.97	1.74	47.47	22.43
May 12	.....do.....	Wheat, 35 bushels; has gotten 47; last year, tomatoes; 800 pounds fertilizer last year.	0–24	20.5	2.49	{13.46 / 9.97}	44.67	37.38
Do...	.....do.....	Wheat, poor.....	.....	20.0	.....	1.74	41.66	30.75
Do...	.....do.....	.....do.....	.....	16.6	2.40	2.87	64.39	31.15
Do...	.....do.....	.....do.....	.....	17.0	.....	2.65	45.81	22.15
Do...	.....do.....	.....do.....	.....	17.4	3.62	1.45	32.49	38.66
May 13	.....do.....	Wheat, 30 bushels.....	0–24	18.8	12.68	2.17	43.25	50.25
Do...	.....do.....	Wheat, poor.....	.....	16.7	9.60	1.68	34.92	36.48
Do...	.....do.....	.....do.....	.....	19.5	13.57	1.97	47.02	35.54
Do...	.....do.....	.....do.....	.....	22.8	8.28	2.04	54.21	32.10
Do...	.....do.....	.....do.....	.....	23.4	14.10	1.79	60.32	25.64
May 14	.....do.....	Wheat, 20 to 25 bushels.....	0–24	19.3	8.10	1.97	55.19	27.10
Do...	.....do.....	Wheat, 30 to 35 bushels or more.	0–24	18.3	11.59	1.71	49.17	21.96
Do...	.....do.....	Wheat, 30 bushels.....	0–24	20.9	8.65	2.22	44.09	22.25
Do...	.....do.....	Wheat, 25 bushels; generally does better.	0–24	23.4	10.26	2.82	48.84	24.10
May 18	Statesville, N. C..	Rye, 15 bushels.....	0–12	9.4	11.12	1.33	24.91	36.03
			12–24	16.0	16.09	1.19	21.40	31.47
Do...	.....do.....	Winter oats, 8 to 10 bushels.	0–12	15.3	39.07	1.66	18.59	42.62
			12–24	23.8	9.63	Tr.	23.05	39.03
Do...	.....do.....	Rye, 6 to 8 bushels.....	0–12	9.3	11.12	1.33	17.46	32.02
Do...	.....do.....	Rye, 25 to 30 bushels.....	0–12	10.9	16.95	1.58	20.28	45.20
Do...	.....do.....	Clover, quite heavy; in bloom.	0–12	10.5	14.64	2.03	22.69	40.54
			12–24	18.4	17.11	1.96	19.18	39.10

Water-soluble constituents of the Cecil clay—Continued.

Date.	Area.	Crop and condition.	Depth of sample, in inches.	Per cent of moisture.	Parts per million of oven-dried soil.			
					Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
May 18	Statesville, N. C.	Wheat, 12 to 15 bushels.	0–12	9.6	10.04	1.34	27.51	42.87
			12–24	19.0	.....	1.96	24.74	40.28
Do.	do.	Wheat, 18 to 20 bushels; good for more.	0–12	10.5	7.88	1.35	25.22	48.64
			12–24	14.2	.....	1.87	20.94	37.44
May 20	do.	Wheat, 25 to 30 bushels.	0–12	8.7	11.04	2.87	22.25	44.16
			12–24	8.8	7.19	0.88	19.90	43.36
Do.	do.	Wheat, 22 to 27 bushels.	0–12	3.1	8.30	1.45	16.30	45.67
Do.	do.	Wheat, 18 to 20 bushels.	0–12	5.0	11.66	2.12	18.97	30.10
Do.	do.	do.	0–12	15.0	17.70	1.18	60.77	25.49
			12–24	30.2	10.22	5.18	21.38	33.78
Do.	do.	do.	0–12	13.0	16.18	1.34	18.15	25.89
Do.	do.	Fallow after cotton (in row)	0–24	24.2	15.48	1.06	28.90	46.44
May 21	do.	Wheat, 25 to 30 bushels.	0–12	7.0	10.84	2.17	18.02	.....
			12–24	19.8	14.21	1.73	19.41	26.70
Do.	do.	Wheat, 4 to 5 bushels.	0–12	10.3	8.41	1.35	17.62	47.57
Do.	do.	Wheat, 3 to 5 bushels.	0–12	8.2	12.10	1.32	19.69	45.76
Do.	do.	Wheat, 3 to 4 bushels.	0–12	7.5	8.72	0.87	23.62	27.47
Do.	do.	Wheat, 2 to 3 bushels.	0–12	9.6	12.83	Tr.	22.49	35.71
Aug. 7	do.	Clover. Good. Top dressed, manured, and subsoiled; 25 bushels wheat. After light shower rain crop value 4 or 5 times that of following sample.	0–12	18.8	2.40	4.89	.....	34.20
			0–24	20.0	24.10	2.73	.....	.....
Do.	do.	Wheat stubble. Very poor. Next field.	0–12	15.6	3.50	8.30	.....	24.20
			0–24	25.5	5.20	7.80	.....	59.30
Do.	do.	Wheat stubble. Poor. Good land, but run down.	0–24	21.1	10.60	1.20	.....	62.10
Do.	do.	Cowpeas after wheat. Good stand and growth. Manured.	0–24	19.3	23.40	0.98	.....	83.80
Aug. 8	do.	Cowpeas after wheat. Good stand. Subsoiled and fertilized. Soil loose and lumpy.	0–12	13.5	13.21	8.10	.....	21.80
			12–24	26.6	14.49	7.60	.....	33.80
Do.	do.	Corn after corn. Poor land. Plowed well this season, and shows some improvement.	0–12	9.7	12.28	2.40	.....	31.80
			12–24	17.6	17.54	1.90	.....	42.60
Aug. 12	do.	Corn after wheat. Strong land. Subsoiled and manured, also fertilizer.	0–12	10.4	11.20	18.70	.....	28.60
			12–24	17.1	14.40	6.50	.....	16.80
Do.	do.	Corn. Poor crop. Good land poorly farmed. Next field to above.	0–12	14.0	11.50	8.80	.....	17.70
			12–24	22.5	12.80	4.90	.....	21.30
Do.	do.	Silage corn. Thick stand, rank growth, and good color. Subsoiled in two directions. Fertilized and top dressed with manure.	0–12	13.2	10.80	22.20	.....	23.10
			12–24	19.0	10.80	8.60	.....	22.90
Do.	do.	Same field as above. Same treatment, except no manure. Corn not so good, paler color, and firing.	0–12	14.0	9.90	6.30	.....	20.70
			12–24	22.5	10.80	4.50	.....	16.80

It will be seen that medium to good crops on the Sassafras loam are recorded from soils giving less than 4 parts per million of phosphates, less than 1 part per million of nitrates, less than 3 parts per million of lime, and less than 8 parts per million of potash. There is no indication that these show actually minimum quantities of plant food that must be present; on the contrary, other determinations made at different times and in different places indicate that plants can thrive with even smaller quantities than these figures show. With such facts before us, it is clearly unnecessary to look for differences in crop yields associated with such differences as are shown in the tables. Furthermore, there is no apparent relation between the yield of crops and the soluble salt content of soils, even where the yields per acre differ as much as from 4 bushels to 25 or 30 bushels.

As bearing upon this point of the association or nonassociation of high analytical figures with large crop yields, no more striking evidence occurs to us than the following extract from a letter written by Mr. Taylor, May 26, while in the field in St. Mary County, Md., and forming a part of his regular reports to the Bureau at Washington:

At Park Hall, upon the farm of Mr. S——, who is recognized as one of the best farmers in the community, I secured some samples of the Leonardtown loam from a wheat field which will produce from 30 to 35 bushels per acre this season. The land was in tobacco last season, upon which barnyard manure and 400 pounds of fertilizer had been used. Nothing was added when the wheat was sown. The land was plowed about 8 inches deep. The soil lacked the usual grayish, ashy appearance of the Leonardtown loam, and owing to cultivation was loose and mellow to a depth of over 2 feet. One of these samples was compared with one taken from another wheat field upon the same type, where the yield would not be over 6 or 8 bushels. This latter land was farmed by negroes, was in wheat last year, and produced a fair crop, so it is said. No manure, but a little guano was used last fall. The ground was uneven on the surface, and below the first 4 or 5 inches the soil was hard and compact. A comparison of the analyses is given below:

Condition.	Per cent of moisture.	Parts per million of oven-dried soil.			
		Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
Good wheat:					
First foot	14.2	2.90	13.22	14.33	24.36
Second foot	19.9	3.72	10.91	12.52	24.80
Poor wheat:					
First foot	14.7	4.72	15.34	7.91	35.40
Second foot	19.9	4.34	11.16	4.15	30.38

It is said here that a virgin soil is the poorest soil they have, and always has to be "brought up" before it will produce anything. I secured a sample from some typical virgin forest land on the Leonardtown loam. The growth was oak, beech, chestnut, and pine. About a quarter of an inch of leaf mould covered the surface. The ground was moist, but compact and polished greatly on the auger, as nearly all of the subsoils of the Leonardtown loam do. The results showed:

Depth.	Per cent of moisture.	Parts per million of oven-dried soil.			
		Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
First foot	12.7	4.64	23.20	15.66	27.84
Second foot	13.8	4.06	22.04	14.33	30.16

The chemical content of this soil is thus seen to be very similar to others of the same type under cultivation.

Just outside of Leonardtown there are two cornfields, one on each side of the road. The two were plowed at the same time, both being sod land, although one had been pastured closely and considerably trampled. One was plowed about 6 inches deep, the other scarcely more than 4 inches deep. One was planted in a very rough, cloddy condition, and the other in a fairly well-pulverized state. It is proposed to make comparative notes on the condition, yields, and chemical content of the soil of these two fields at later visits during the growing season. On the 18th samples were taken from each and analyzed. The corn was not yet up.

Condition.	Per cent of moisture.	Parts per million of oven-dried soil.			
		Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
Cloddy field:					
First foot	18.3	3.36	31.72	31.42	29.28
Second foot	23.4	8.00	24.96	15.81	32.64
Smooth field:					
First foot	18.2	3.36	42.09	24.4	37.82
Second foot	18.8	6.10	21.96	18.91	28.06

About a mile west of Mechanicsville I found, on the Norfolk loam, a wheat field, which presented a rather interesting feature. Down through the center of the field there was a somewhat low-lying swale-like strip, 2 or 3 rods wide, upon which the wheat was very heavy, rank, and tall. From this strip, which would yield at least 30 bushels per acre, I took a sample. The soil was loose, mellow, and dark colored to a depth of 30 inches, where it began to grow more compact and yellower. Just 10 feet from the first sample, where the yield will not be over 12 bushels per acre, I took another. At this place the surface foot was very similar to that of the other, while the succeeding 2 feet were much more compact, hard, and crumbly. Analyses of the two samples give the following figures:

Condition.	Per cent of moisture.	Parts per million of oven-dried soil.			
		Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
Good wheat:					
First foot	13.5	6.96	4.87	10.44	20.18
Second foot	17.1	5.70	2.76	13.44	19.00
Poor wheat:					
First foot	10.7	5.04	3.02	8.80	26.00
Second foot	15.2	5.31	3.18	10.62	24.07

The difference in the yield of wheat in these two spots is probably not due either to cultivation nor to fertilization, but to the fact that there has been a gradual accumulation of material in the lower from the higher level, and the heavy growth of wheat can, therefore, hardly be considered the result of natural field conditions. The analyses of the two samples are of interest, however, in that they show that the amount of plant food present in the two cases is not materially different, but that the physical condition of the soil precludes the possibility of the plant receiving it. I dug a hole in the ground where the good wheat was growing and found that the roots had penetrated to a depth of 54 inches, while those of the poor wheat had gone down only about 26 inches.

I have taken several samples from a tobacco field on the Windsor sand just north of town. The grower is using 400 pounds of bone and potash per acre, and is applying it in the row. I have arranged with him to leave two rows across the field unfertilized from which to get samples and notes for comparison later on in the season. Two samples taken from the field on Tuesday, four days after the fertilizer was applied, show the following results, one-half to three-fourths inch of rain having fallen on Sunday:

Condition.	Per cent of moisture.	Parts per million of oven-dried soil.			
		Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
Fertilized:					
First foot	8.1	6.60	7.70	9.90	25.74
Second foot	10.4	3.36	2.57	7.50	23.30
Not fertilized:					
First foot	9.0	3.85	4.90	8.63	20.90
Second foot	9.7	3.92	1.80	11.20	21.00

The results so far obtained from corn and tobacco lands, where fertilizers have been recently applied, show a slightly greater salt content than fallow, grass, or wheat lands.

The following table shows the average composition of the first, second, and third foot of soil, from 86 borings made in the Salem and St. Mary County areas:

Average of results for different depths in the Salem and St. Mary County areas.

Depth.	Parts per million of oven-dried soil.			
	Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
First foot	7.93	8.99	13.18	24.06
Second foot	7.03	7.78	11.10	25.14
Third foot	7.16	2.18	8.74	22.02

It is apparent from this that there is no material difference in the dissolved salt content of the first, second, and third foot, for if plants do well with the quantities indicated by the above minimum figures, the small differences shown in the averages for the first, second, and third

foot, when the lowest is 2 or 3 times as great as the minimum found, have no significance. We must conclude, therefore, strange as it may seem at first, that the soil proper does not contain materially more soluble plant food than does the subsoil.

The average of 147 determinations by Taylor and Mooney show the following values in parts per million of dry soil:

Phosphoric acid	7.64
Nitric acid	5.47
Calcium	11.67
Potassium	22.74

While these values will undoubtedly vary somewhat as a result of wider investigations, it is believed that they represent closely the average figures for the great majority of cultivable soils as regards these several constituents, which the procedure used in this investigation will show; and so far as the investigations have been carried, it may be stated, no evidence has yet been found, except possibly in occasional samples, where the quantity of any one of these necessary plant foods was below the amount necessary for the support of a medium to good crop.

It has been deemed worth while, in this connection, to obtain a more definite idea as to the concentrations existing in actual soil solutions. For this purpose some large samples (about 5 pounds) of soils were forwarded to the laboratory from the field by parties working in southern Maryland and the Salem area in New Jersey. These samples were all examined by the procedure described in this bulletin, but no unusual features being disclosed the figures obtained are not given here. They were then filtered under a powerful centrifugal force in the apparatus devised by Briggs. The samples of Norfolk sand were too dry when received in the laboratory to yield any solution in the centrifugal machine, or at least enough to serve for a satisfactory analysis, although they had not become "air dry." These samples were therefore moistened, mixed thoroughly, and allowed to stand several days to come to an equilibrium before the moisture was extracted from them. A brief description of the samples, with the analytical data obtained, is given in the following table, the per cent moisture meaning that which the sample contained when placed in the centrifuge. It has been thought of sufficient interest to include, also, a statement of the results on the basis of dry soil, as well as in terms of parts in solution.

Analyses of soil moisture removed from fresh soils by the Briggs centrifuge.

Date.	Area and soil.	Crop.	Condition.	Per cent moisture.	Parts per million.							
					Phosphoric acid (PO_4).		Nitric acid (NO_3).		Calcium (Ca).		Potassium (K).	
					Soil moisture.	Dry soil.	Soil moisture.	Dry soil.	Soil moisture.	Dry soil.	Soil moisture.	Dry soil.
May 1	Maryland—Leonardtown loam.	Wheat..	Good ...	22.0	6.30	1.38	1.44	0.32	16.20	3.56	21.60	4.75
Do..	.....do.....	....do...	Poor....	25.2	9.75	2.45	4.80	1.21	8.50	2.12	19.25	5.10
Do..	.....do.....	....do...	Good ...	17.6	8.40	1.48	4.08	.72	21.60	3.80	38.40	6.75
Do..	Maryland—Sassafras loam.	Clover..	....do...	19.7	5.28	1.04	2.24	.44	17.82	3.51	18.48	3.64
Do..	.....do.....	Corn....	Medium	17.5	7.50	1.27	2.60	.44	13.40	2.28	36.00	6.12
June 8	New Jersey—Sassafras loam.	....do...	....do...	18.3	7.74	1.42	4.47	.82	82.81	15.15	24.77	4.43
Do..	.....do.....	Wheat..	Good ...	18.8	7.20	1.35	7.20	1.35	44.40	8.34	33.60	6.31
Do..	.....do.....	....do...	Poor....	20.0	7.00	1.40	.40	.08	26.90	5.38	24.40	4.88
June 16	.....do.....	Corn....	Good ...	17.3	8.40	1.45	1.56	.27	24.18	4.18	24.96	4.32
May 1	Maryland—Norfolk sand.	Forest ..	Poor....	10.0	5.00	.50	10.60	1.06	18.00	1.80	31.00	3.10
June 8	.....do.....	Corn....	Good ...	11.85	10.80	1.28	64.80	7.68	35.84	4.24	31.04	3.68
Do..	.....do.....	Wheat..	....do...	10.7	18.25	1.95	1.50	.16	44.80	4.80	30.80	3.30
June 16	.....do.....	....do...	Poor....	11.2	7.50	.84	.66	.07	37.62	4.21	23.76	2.65
Do..	.....do.....	Corn....	Medium	10.6	9.00	.95	3.96	.28	64.50	6.83	34.56	5.08

The figures presented in this table showing the concentration of the different constituents in the soil moisture on the whole are remarkably uniform, even though, as will be observed, the amounts of water initially present in the soils varies from 10 to 25 per cent, and 3 widely divergent soil types are involved. Considering such differences as do exist (which are made as pronounced as possible by the method of stating them), it seems impossible to correlate them with the field observations as to actual crop conditions existing upon the soils. This table would lead then to the same conclusions as were drawn from the results obtained by the conventional method we have been considering above, i. e., that with occasional exceptions the composition of the soil solution and the concentration (per unit of solution, volume or mass) is about the same in all cutivable soils, and that it is impossible to account for observed crop differences by such differences as the chemical examinations show. As a necessary consequence, it follows from this latter conclusion that these differences revealed by analysis must be of a minor or vanishing importance as a factor in crop yields. It should be remembered, of course, that the figures in this table represent a state of equilibrium between the soil solution and the solid components of the soil which, as has been pointed out

above, is not attained by our conventional method, and the actual quantities are in consequence of a somewhat different order. While these figures emphasize the conventional character of the method, they are a very strong justification of it as a satisfactory one for comparative purposes.

It appeared desirable to examine this point further with soils representing a wider range of physical characteristics and crop values. An opportunity to examine fresh soil samples fulfilling these conditions has not yet occurred, but it was deemed worth while to select a number of samples from the collection of the Bureau, even though they had been thoroughly air dried over periods of a year or more, and, as will be presently shown, it was foreseen that they would probably yield results somewhat too high. This may have been compensated in part by the fact that, after moistening, the samples were allowed to stand for but twenty hours before being placed in the centrifuge. The results obtained follow:

Analyses of solutions extracted from soils in the collection of the Bureau by the Briggs centrifuge.

Soil.	Per cent soil moisture.	Parts per million.							
		Phosphoric acid (PO_4).		Nitric acid (NO_3).		Calcium (Ca).		Potassium (K).	
		Soil moisture.	Dry soil.	Soil moisture.	Dry soil.	Soil moisture.	Dry soil.	Soil moisture.	Dry soil.
Hagerstown loam, Maryland	17.6	7.01	1.23	68.42	12.04	141.11	24.84	51.58	9.08
Do	19.0	5.62	1.07	68.42	13.00	134.72	25.60	50.53	9.60
Norfolk sand, Maryland	7.6	7.01	.53	10.53	.80	141.11	10.72	44.21	3.36
Tobacco soil, California	13.0	17.54	2.28	394.74	51.32	564.44	73.37	42.10	5.47
Plains marl, Nebraska	13.5	14.02	1.89	27.37	3.70	85.28	11.51	73.68	9.95
Tobacco soil, Florida	7.4	9.82	.73	10.53	.78	208.06	15.40	76.84	5.69
Cecil clay, North Carolina	51.0	2.52	1.29	2.52	1.29	6.18	3.15	14.74	7.52
Light loam, Pennsylvania	18.5	5.62	1.04	3.26	.60	107.12	19.82	22.53	4.17
Heavy loam, Pennsylvania	20.9	11.24	2.35	2.32	.41	138.02	28.85	52.63	11.00
Loess, Illinois	14.1	8.42	1.19	5.79	.82	393.46	55.48	48.42	6.83
Hagerstown clay loam, Maryland	15.9	9.82	1.56	11.58	1.84	218.36	34.72	47.37	7.53
New Mexico sand, New Mexico	9.2	7.72	.71	2.21	.20	635.72	58.49	110.52	10.17
Adobe, California	17.6	14.02	2.57	4.21	.86	203.94	35.89	35.79	6.30
Adobe remoistened	18.3	3.51	.64	9.47	1.73	179.22	32.79	61.05	11.17

With a wider range in the amounts of water present, as well as in the crop values of the soils, this table again justifies the conclusions already stated as to the return of the soil solution, its relation to crop yields, and the validity of the conventional method for the purpose of the investigation described in this Bulletin.

Several examinations of a soil from Takoma, Md., showed only a trace of nitrates and of phosphates, even by the sensitive methods that are now used, and a very infertile clay soil from Brightwood, in

the District of Columbia, showed only two parts of nitrates and only a trace of phosphates. The soil from Brightwood, however, when brought into a proper physical condition, has been shown to support a vigorous growth of clover and of wheat in pots in the laboratory without the application of chemical fertilizers. On the Takoma soil a fairly satisfactory lawn can be established by bringing the soil into the proper physical condition, although nothing be added to the soil. The following table shows the character of solutions derived from these two soils:

Water-soluble constituents of a sandy loam from Takoma, Md., and a clay from Brightwood, D. C.

Locality.	Parts per million of oven-dried soil.			
	Calcium (Ca).	Potassium (K).	Nitric acid (NO_3).	Phosphoric acid (PO_4).
Takoma, Md	39.2	13.4	Tr.	Tr.
Do	39.2	22.4	Tr.	Tr.
Do	95.3	17.3	Tr.	Tr.
Do	42.8	17.5	Tr.	Tr.
Brightwood, D. C	18.4	21.0	2.1	Tr.

An analysis of the soil from Brightwood by the procedure of the Association of Official Agricultural Chemists, where a solution of the soil is obtained by digesting with hot concentrated hydrochloric acid, gave lime (CaO) 0.26 per cent, magnesia (MgO) 0.02 per cent, potash (K_2O) 0.29 per cent, and phosphoric acid (P_2O_5) 0.07 per cent, figures which would not necessarily suggest an infertile soil.

On the other hand, many cases might be cited where the usual methods would indicate the inability of a soil to support vegetation, though as a matter of fact such vegetation does exist. In illustration some analyses recently made in the routine work of the Bureau might be cited. These soils and subsoils from southern forest lands were reported to be maintaining a good growth of oak, pine, and underbrush of hickory, chinquapin, and huckleberry, although the plant food "available," according to the official method, is exceedingly low. The analyses of the aqueous extract by the methods described in this bulletin indicate that the soil solution is probably about normal in concentration as compared with other soils from humid areas.

Analyses of certain soils, showing differences in results by acid digestion and aqueous solution methods.

Sample No.	Depth of sample in inches.	Results obtained by methods of the Official Association of Agricultural Chemists, stated in percentage.			Results obtained by extraction with water, stated in parts per million of air-dried soils.		
		Potash (K_2O).	Lime (CaO).	Phosphoric acid (P_2O_5).	Potassium (K).	Calcium (Ca).	Phosphoric acid (PO_4).
8286	0–4	0.034	Tr.	Tr.	24.5	9.2	16
8287	4–12	.043	0.0008	Tr.	10.5	5.1	18.5
8288	0–4	.060	.0008	Tr.	7	3.1	31.5
8289	4–12	.048	Tr.	0.0025	19.5	4.1	Tr.
8290	0–4	.046	Tr.	.0021	15.5	3.1	47.5
8291	4–12	.036	Tr.	.002	16.5	4.1	21
8292	0–4	.032	0.0008	.0025	25	2	10.5
8293	4–12	.037	Tr.	Tr.	52	16.4	13
8294	0–4	.042	Tr.	.004	57	2	1
8295	4–12	.055	Tr.	.0034	56	1	.8
8296	0–4	.076	Tr.	.004	65	1	1
8297	4–12	.161	Tr.	.005	60	2	.7

Realizing the importance and gravity of the position forced upon the Bureau by the multiplication of such evidence, an examination has been made of a large number of different types of soils from different parts of the United States, air-dried samples in the collection of the Bureau being used in the determinations. A difficulty at once presented itself here, in the possibility that the drying out of the samples might change the solubility of the soils, a difficulty which seemed the more probable in view of the results formerly obtained in this Bureau[a] when examining the electrical conductivity of saturated soils before and after drying.

In his work in this Bureau, King has found this effect of the drying out of a soil upon its solubility to be quite marked, in some cases and for certain constituents, but it was deemed desirable to examine a few cases with regard to those constituents which have been considered in this bulletin. There were used for this purpose a heavy black clay and a lighter truck soil collected near Glencarlyn, Va., a light gravelly and a somewhat lighter soil from near Mount Pleasant, D. C., on which grass and clover were growing, and samples from a lawn and a garden, respectively, in the grounds of the Department of Agriculture, the last two having recently received heavy applications of fertilizers.

The samples were thoroughly mixed, one portion in each case being taken for immediate analysis; a second portion was air dried as quickly as possible by being spread in a thin layer and exposed to the sun until the moisture present was brought below 3 per cent; while a third por-

[a] Bul. No. 8, U. S. Dept. Agr., by Milton Whitney and Thomas H. Means, p. 13 (1897).

tion was carried to dryness in a hot-water oven, remoistened, and again dried out, this process being repeated three times. It was found that the drying of the soils not only affected the solubility of mineral constituents of the soil, as shown in the following table, but the organic matter as well:

Effect of drying soils upon the solubility in water of certain constituents.

Description.	Condition.	Parts per million of oven-dried soil.			
		Phosphoric acid (PO_4).	Nitric acid (NO_3).	Calcium (Ca).	Potassium (K).
Black clay collected near Glencarlyn, Va...	Fresh.....	8.6	7.1	7.8	15.2
	Air dried	9.6	8.5	12.7	21.9
	Oven dried...	12.7	15.8	90.2	34.9
Truck soil collected near Glencarlyn, Va...	Fresh.....	6.7	23.6	10.3	16.4
	Air dried.....	10.4	30.2	15.5	20.4
	Oven dried...	15.7	25.5	83.5	20.6
Gravelly soil collected near Mount Pleasant, D. C.	Fresh.....	11.9	5.2	69.0	22.2
	Oven dried...	23.8	33.2	127.4	93.0
Soil collected near Mount Pleasant, D. C....	Fresh.....	9.1	2.3	20.6	11.2
	Air dried	11.9	3.6	33.0	11.5
	Oven dried...	13.6	19.2	38.0	20.0
Soil from lawn, recently fertilized	Fresh.....	9.8	273.5	125.4	65.5
	Oven dried...	19.0	200.0	257.1	174.0
Soil from garden, recently fertilized	Fresh.....	68.8	149.1	72.4	83.6
	Air dried	43.2	142.6	70.5	91.8
	Oven dried...	63.1	139.7	174.1	125.3

The aqueous extracts of the air-dried samples were somewhat colored, and the extracts of the oven-dried samples quite strongly colored, although extracts of the fresh samples were quite colorless. An inspection of the figures in the table shows a decidedly increased solubility with respect to the important constituents indicated, and this increase seems to be always produced by drying the soils, except where the constituents are present in unusually large amounts as the result of the recent application of fertilizers. Curiously, this increased solubility seems to be characteristic of the nitrates, as well as the other constituents, a fact suggesting the importance of further investigation along this line.

Recognizing, then, that in general there is a tendency toward an increase in the solubility of constituents, notably potassium, calcium, and phosphoric acid, on drying out a soil sample, nevertheless it is believed that the analyses of the air-dried type soils from the Bureau's collection have a value for purposes of comparison. In all cases a composite sample made up of four or more collection samples was used.

Analyses of water extracts of type soils.

Type.	Remarks.	Parts per million of air-dried soil.			
		Calcium (Ca).	Potassium (K).	Phosphoric acid (PO_4).	Nitric acid (NO_3).
Allegan gravelly loam, Michigan	Productive soil for general crops	37.6	40.7	37.8	129.0
Alloway clay, New Jersey	Meadow, and some grain	27.2	25.0	10.5	25.2
Cecil loam, New Jersey	Productive wheat soil	2.0	48.5	3.5	5.5
Cecil loam, Virginia and Maryland	Productive in Maryland; unproductive in Virginia; wheat.	33.4	29.1	10.5	11.5
Cecil mica loam, Maryland	Fair corn soil	10.4	22.4	14.0	12.0
Cecil sandy loam, Virginia	Poor corn soil; average 10 bushels per acre.	12.5	14.4	23.8	9.5
Clarksville clay loam, Tennessee	Productive soil; wheat and corn	2.1	64.0	12.5	13.1
Clarksville loam, Tennessee	Productive soil; hay and corn	18.8	23.7	14.0	11.5
Clarksville silt loam, Tennessee	Productive; grain and grass	4.2	36.5	7.6	9.2
Clarksville stony loam, Tennessee	Poor soil; mainly fruit	27.2	22.5	26.6	81.0
Collington sandy loam, Maryland	Productive soil; wheat and nursery stock.	8.3	31.5	3.5	8.0
Conestoga clay, Virginia	Productive soil; wheat and tobacco	16.7	19.0	8.3	13.3
Conestoga loam, Pennsylvania	Fairly productive for wheat	91.9	27.5	7.0	210.5
Conowingo barrens, Maryland	Unproductive	6.3	22.6	11.2	5.2
Conowingo clay, North Carolina	Productive wheat soil	4.2	12.3	12.0	9.5
Delavan silt loam, Illinois	Productive soil; corn and small grain.	20.9	17.6	7.6	7.5
Dunkirk clay, New York	Very productive for wheat, grass, and grapes.	60.6	48.4	14.0	32.3
Durham sandy loam, Virginia	Unproductive for corn; good watermelon soil.	39.7	32.5	14.0	10.5
Edgemont stony loam, Virginia	Unproductive; used only for mountain peaches.	8.4	35.5	12.0	2.7
Hagerstown clay, Virginia	Very productive for grass	10.4	28.9	9.0	4.7
Hagerstown loam, Pennsylvania	Very productive for wheat and corn	16.7	25.8	7.0	9.5
Hagerstown shale loam, Pennsylvania.	Naturally unproductive	25.1	51.0	11.0	6.1
Hartford sandy loam, Connecticut (soil).	Connecticut and Sumatra tobacco	25.0	40.0	5.6	6.0
Hartford sandy loam, Connecticut (subsoil).	do	41.8	51.5	4.2	7.5
Houston black clay, Texas	Productive rice land	8.4	5.2	18.0	9.2
Iredell clay loam, Virginia	Poor soil	2.1	22.5	9.0	4.3
Lintonia loam, Mississippi	Productive cotton soil	39.7	24.5	22.4	10.5
Memphis silt loam, Mississippi	Poor soil; one-third bale cotton per acre.	4.1	35.5	5.6	4.2
Miami black clay loam, Ohio	Very productive corn soil; 60 to 80 bushels per acre.	20.9	47.0	11.3	31.5
Miami clay loam, Ohio	Productive wheat soil; 40 bushels per acre.	4.2	84.0	9.5	7.2
Miami gravelly loam, New York	Productive wheat and corn soil	16.7	18.3	28.0	22.1
Miami sand, Indiana	Truck soil	37.6	12.0	17.5	8.9
Miami silt loam, Illinois	Productive corn soil; 40 to 60 bushels per acre.	16.7	16.4	5.0	11.7
Miami stony loam, Michigan	Productive, general farming crops	18.8	15.5	32.2	25.2
Orangeburg clay, Alabama	Productive cotton soil	213.2	47.3	7.5	11.5
Orangeburg loam, South Carolina	Fair cotton soil	2.1	25.4	21.0	7.4
Orangeburg sandy loam, Alabama	Poor cotton soil	4.2	39.5	8.3	1.4
Penn loam, Pennsylvania	Productive wheat, corn, and grass soil.	31.3	68.5	10.3	20.7
Penn sandy loam, Pennsylvania	Fair corn soil	6.3	18.4	14.0	5.7

Analyses of water extracts of type soils—Continued.

Type.	Remarks.	Parts per million of air-dried soil.			
		Calcium (Ca).	Potassium (K).	Phosphoric acid (PO_4).	Nitric acid (NO_3).
Podunk fine sandy loam, Connecticut.	Broadleaf tobacco soil	64.8	23.2	10.5	73.5
Sandhill, North Carolina	Unproductive	4.2	16.4	11.2	14.2
Sassafras loam, Maryland	Very productive; general farm crops.	20.9	45.5	9.0	11.0
Sassafras sandy loam, Alabama	Good corn and peach soil	31.3	24.7	14.0	6.7
Suffield clay, Connecticut and Massachusetts.	Unproductive	20.9	55.2	8.3	39.0
Susquehanna clay, Maryland	.....do	31.4	17.2	25.2	5.2
Susquehanna gravel, Maryland	.....do	33.4	21.0	21.0	50.0
Triassic stony loam, Connecticut	Productive wheat and grass soil	33.4	24.5	22.4	13.2
Waverly silt loam, Illinois	Fair corn soil	20.9	13.1	7.0	4.0
Willis sand, Texas	Very poor soil	12.5	27.5	2.8	10.5
Windsor sand, Maryland	.....do	6.3	14.5	18.2	4.2
Yazoo clay, Mississippi	Very productive cotton soil; 1½ to 2 bales per acre.	29.2	50.0	8.0	9.5
Yazoo loam, Mississippi	Good cotton soil; 1 bale per acre	16.7	30.0	9.3	8.0
Yazoo sandy loam, Mississippi	Poor cotton soil; one-third bale per acre.	16.7	45.2	5.6	6.0

The types range in agricultural value from the least productive to the most fertile soils in the country; but from the figures in the table it is at once evident that, as in the case of results given above from the field work, no correlation can be made between the amount of plant food as shown by the analyses and the known crop values of the soils; and that while the differences in the figures may even be somewhat larger than those obtained from fresh soil samples, considering their actual significance they vary but little and are of the same order.

The Bureau was fortunate in having a few samples of soil from the famous Hoos and Broadbalk fields at the Rothamsted Station in England, and it is deemed worth while to give the results of an examination of them here. The brief description given will enable one to find the past history of these soils by referring to Sir Henry Gilbert's report.[a]

[a] Memoranda of the field and other experiments at Rothamsted, Herts. Fifty-third year, 1896.

Analyses of water extracts of soils from the barley plots, Hoos field, and wheat plots, Broadbalk field, Rothamsted, England.

Description.[a]	Parts per million of air-dried soil.			
	Calcium (Ca).	Potassium (K).	Phosphoric acid (PO_4).	Nitric acid (NO_3).
B_1a	135.8	17.6	19.6	26.2
B_3a	123.3	37.8	10.5	22.1
B_4a	129.6	39.9	16.8	13.1
W_3	131.7	13.4	11.2	11.5
$W_{10}a$	133.8	18.5	11.9	10.0
W_{11}	152.6	9.4	12.6	12.0
W_{13}	131.7	30.7	14.7	10.5

[a] Samples B_1a, B_3a, and B_4a: From the Hoos field, devoted to the growth of barley year after year since 1852, when the first experimental barley crop was grown. The previous crop history was—1847, Swedish turnips, with dung and superphosphate of lime, the roots being carted off; 1848, barley (with clover); 1849, clover; 1850, wheat; 1851, barley manured with ammonium salts.

Sample B_1a: Two hundred pounds ammonium salts per acre, annually, consisting of equal parts of commercial sulphate and muriate, except in 1887, when there were used 225 pounds ammonium sulphate, equivalent in nitrogen to the ammonium salts previously and since used. Average yield, 1852–1893, 28½ bushels.

Sample B_3a: Two hundred pounds ammonium salts used annually; 200 pounds sulphate of potash annually, except 1852–1857, when 300 pounds were used; 100 pounds sulphate of soda annually, except 1852–1857, when 200 pounds were used, and 100 pounds magnesium sulphate used annually. Average yield, 1852–1893, 31½ bushels.

Sample B_4a: Same as B_3a, except that 3½ hundredweight of superphosphate per acre was annually used. Average yield, 1852–1893, 43⅝ bushels.

Samples W_3, $W_{10}a$, W_{11}, and W_{13}: From the Broadbalk field, grown in wheat continuously since 1844. Previous croppings—1839, turnips, with farmyard manure; 1840, barley; 1841, peas; 1842, wheat; 1843, oats; last four crops unmanured.

Sample W_3: Unmanured continuously. Average yield, 1852–1893, 13¾ bushels.

Sample $W_{10}a$: Four hundred pounds ammonium salts per acre, 1845 and since; mineral manure, 1844. Average yield, 1852–1893, 21⅞ bushels.

Sample W_{11}: Four hundred pounds ammonium salts and 3½ hundredweight superphosphate per acre annually. Average yield, 1852–1893, 30⅛ bushels.

Sample W_{13}: Four hundred pounds ammonium sulphate, 3½ hundredweight superphosphate, and 200 pounds sulphate of potash annually, except that up to 1858, inclusive, 300 pounds of sulphate of potash annually were used. Average yield, 1852–1893, 30¾ bushels.

The figures given above are comparable with those for other soils which have already been cited, except possibly in the case of calcium. But with regard to this constituent the Rothamsted soils must be considered as in a special class, since they contain relatively large proportions of calcium carbonate; in fact all the samples examined here effervesced strongly on the addition of hydrochloric acid. Moreover, all these Rothamsted samples were sifted material containing only the finer particles from the original soils. The sample marked W_3 is from the field on which wheat has been grown continuously for upward of fifty years without manure or other fertilizers, but the figures given would place it very close to W_{11}, a sample from a field continuously manured and yielding averages through twenty-one-year periods varying from 26½ to 33⅝ bushels of wheat per acre. It appears evident that the decreased yield from the continuously unmanured wheat plot has not been due to loss of water-soluble material, or rather that there has been no permanent disturbance of the solution equilibrium and concentration. This will be brought out more strikingly in discussing the rotation of crops.

It is clearly brought out in the foregoing tables that there are no wide variations in the amounts of material going into solution when these various soils, so widely different in their other characteristics, are acted on by a definite proportion of water for a short but definite length of time. The form in which the figures are stated is probably the one in which the differences would appear to be greatest; but when one considers the absolute magnitude of the quantities and their proportional relation to the amount of soil from which they are taken, one is easily led to the view just expressed, or, in other words, all types of soils furnish about the same amount of plant food when treated with the same proportion of water, other conditions—as time, temperature, etc.—being also the same. That this might have been expected from *a priori* considerations has already been pointed out in considering the chemical nature of the mineral components of the soil, but the experimental confirmation brought out in the results presented here is of the first importance in putting this idea on the basis of a working hypothesis for the direction of future investigations.

It is further evident from these deductions that a soil normally containing 20 per cent of water will have actually twice as much salt in solution as the same or a different soil having 10 per cent of water, although the solution in the two cases would be of about the same concentration. Furthermore, that if the amount of water were reduced through root action, the salt not being taken up as rapidly as the water, some of the salts might go out of solution, although in a form more or less readily soluble provided there was sufficient water to dissolve them. It seems probable, also, from our observations that the movement of the water in the soil is much more rapid than the movement of salts contained in the water, as the surface influence of the soil grains upon the saline material, or what is generally recognized as adsorption, is sufficient to retard to a very large extent the movement of salts and makes it a difficult and tedious process to leach the salts out by the continual passage of water.

From the results of the other investigations described and the figures given in the preceding tables, the conclusion seems inevitable that all our principal soil types, in fact, practically all cultivable soils, contain naturally a nutrient solution which varies within comparatively narrow limits with regard either to composition or concentration and which is usually sufficient for plant growth. Apparently, therefore, all these soils are amply supplied with the necessary mineral plant foods and these plant foods are not in themselves a matter of such paramount importance to the agriculturist, for their supply as regards the plant is determined by the supply of soil moisture which the crop can obtain from the soil. The chemical analysis of a soil can not in itself, therefore, throw much light upon the problem of fertility, but, when attempting to control the factors governing

crop yield, attention must be directed to the mechanical condition of the soil as affecting the supply of soil moisture, with its dissolved mineral nutrients, to the effects of climate, to rotation, etc. These several factors will therefore be discussed in the succeeding chapters before returning to a consideration of the problems presented by fertilizer practice in the light of the views developed in this bulletin.

THE INFLUENCE OF CLIMATE UPON THE YIELD OF CROPS.

The influence of climate due to latitude and physiographic position upon the economic distribution of crops is apparent to everyone. It restricts the commercial growth of a large number of plants, such as the orange, banana, pineapple, guava, lemon, rubber, and the like, of tropical or semitropical countries. The difference in the vegetation between the arid tropical and humid tropical countries is pronounced. The much higher yield of wheat and corn in our Northern States as against that of the Southern States is marked. Cotton is limited in its distribution; the sugar beet of high sugar content is confined to a comparatively narrow belt across the northern part of our country. The effect of a simple covering of glass, or of cheese cloth, is familiar to all, while quite recently the influence of such a covering over the tobacco fields of Connecticut has made it possible to grow the thin-textured wrapper leaf characteristic of Sumatra tobacco instead of the heavy coarse-veined leaves of the seed-leaf variety grown in the open field. The influence of climate on the yield of crops is likewise very strikingly shown in the difference in yield from year to year on the same field under presumably the same methods of fertilization and cultivation. This is clearly brought out in the Rothamsted experiments[a] in the growth of wheat and grass.

The yield of wheat grown continuously for fifty years, from 1852 to 1901, on a plot unmanured during that time has varied from 5⅜ bushels in 1879 to 23¾ bushels in 1875, 23⅝ bushels in 1859, and 22⅜ bushels in 1894. The average yield for forty years was 15 bushels. The largest average yield over the same period for any of the fertilized plots was 33½ bushels; the smallest yield being 16¼ bushels in 1879, and the largest 53⅝ bushels in 1863. The average yield during eight years preceding this period was about the same on the unfertilized and the fertilized plot. The average yield on the unfertilized plot for the second twenty-year period was 12¾ bushels against 17 bushels for the first period of twenty years, while on the particular plot which was fertilized and which gave the largest average yield, the yield during the latter twenty years was 31 bushels as against 35¼ bushels for the first twenty years.

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[a] Agricultural investigations at Rothamsted, England, during a period of fifty years, by Sir Joseph Henry Gilbert, Bul. 21, Office Exp. Sta., U. S. Dept. Agr., p. 158.

It is a significant fact, also, that where the annual application of the fertilizer has been discontinued, the effect is at once apparent in the smaller yield of crops. In other words, on a soil which has a natural capacity for 13 or 15 bushels of wheat as these Rothamsted soils seem to have where wheat is grown continuously and fertilizers have not been used for fifty years, the application of certain fertilizers has increased the yield to 30 bushels per acre, but to maintain that yield a constant annual application of fertilizer has to be given and subsequent applications merely maintain but do not increase the yield.

The Rothamsted experiments cited above indicate that the extreme variations due to climatic conditions are even greater than the difference due to fertilizers where the same methods of cultivation are used.

The following table shows the average yields per acre for 20 years in the grass experiments at Rothamsted with the average of the 4 best years, the 4 worst years, for all plots, for unmanured plots, and for the 4 best plots:

Comparative statement of yields of grass on Rothamsted experiment plots.

Class.	Average, 20 years.	Average, 4 best years.	Comparison of 4 best-year average with 20-year average.	Average, 4 worst years.	Comparison of 4 worst-year average with 20-year average.
	Pounds.	*Pounds.*	*Per cent.*	*Pounds.*	*Per cent.*
All plots	4,238	5,071	120	2,797	66
Unmanured	2,535	3,295	130	1,420	56
Four best plots	6,572	7,314	111	5,358	82

The figures show that the fertilizers have not only increased but have apparently regulated the yield, so that there is considerably less variation on the fertilized plots between good and poor seasons than on the unfertilized plots. There is the greatest variation on the unmanured plots, the average of the 4 best years being 130 per cent of the average for the 20 years, while for the 4 worst years it fell to 56 per cent.

The following table gives, in the second column, the actual yield from all of the grass plots from 1856 to 1875, inclusive, while in the fourth column the figures are arranged in the order of yield from the season of 1870, giving the lowest aggregate yield, to the season of 1869, giving the highest. The figures bring out very strikingly the influence of the season on the yield of the crop. It is evident also from these figures that the variation due to climate is as large as the variation due to fertilizers.

Annual yield of all grass plots in Rothamsted experiments, 1856–1875, arranged chronologically and in order of quantity.

Year.	Yield.	Year.	Yield.
1856	84,614	1870	48,156
1857	88,265	1874	51,706
1858	88,640	1865	62,032
1859	88,452	1873	67,782
1860	85,412	1872	76,319
1861	94,315	1875	81,184
1862	94,900	1856	84,614
1863	94,594	1860	85,412
1864	91,722	1868	85,940
1865	62,032	1857	88,265
1866	89,516	1859	88,452
1867	92,190	1858	88,640
1868	85,940	1866	89,516
1869	121,802	1871	91,426
1870	48,156	1864	91,722
1871	91,426	1867	92,190
1872	76,319	1861	94,315
1873	67,782	1863	94,594
1874	51,706	1862	94,900
1875	81,184	1869	121,802

Average first period (10 years)	88,798
Average second period (10 years)	81,333
Average whole period	83,948

It is recognized that in our own soils when under intensive cultivation, as in the truck and the tobacco areas, large applications of manure and fertilizers are often used, amounting to from 2 to 5 carloads of the former and 2,000 or 3,000 pounds per acre of the latter, but the maximum effect from these is quickly obtained and the yields can be maintained only by continued large applications.

It will be seen from the results obtained by this Bureau that these large annual applications of stable manure, or of high-grade fertilizers, do not apparently change permanently the chemical composition of the soil as determined by chemical analysis of the aqueous extracts; that is to say, immediately after the application the influence of the fertilizer can be seen in the increase in the soluble salt content of the soil; but not only is this comparatively slight, but fields that have been annually treated in this way for a number of years do not show on the average appreciably more water-soluble plant food than adjoining soils upon which no such applications have ever been made.

These observations indicate obviously that fertilizers do sometimes increase the yield of crops and maintain a larger average yield over a period of years. But it is not obvious, as has been claimed, that such results indicate in the unfertilized soil an amount of available plant

food actually insufficient for the need of crops. We have seen that the effect of climate on the yield of crops is very marked. We know that cultivation changes the climatic conditions of the soil—that is, it changes the relation of the soil to moisture and, probably, also to temperature. It also changes the character of the atmosphere coming in contact with the root system. We know that stable manure and lime, for example, have a marked influence upon the texture of the soil, and, therefore, indirectly upon the climatic conditions. It seems possible that other fertilizer materials may produce effects of a similar character.

If fertilizers have any influence upon the texture of the soil, or upon the movement of soil moisture, they will not only influence the supply of water which will be delivered to the plant, but also the supply of nutrient materials normally contained in this water. The problem would then come into the domain of soil physics rather than into that of soil chemistry. The important practical inference, if this is so, is that fertilizers have to a certain extent the same effect as cultivation and cropping; but in a majority of cases it is undoubtedly better to depend upon efficient methods of cultivation and cropping than to rely upon fertilizers while at the same time neglecting to give proper attention to the physical condition of the soil. The effect due to cultivation is also more permanent than the effect due to fertilizers. Furthermore, the influence of fertilizers on the yield of crops is not proportional to the amount of fertilizer added, as it frequently happens that a small application is quite as efficient as a larger application.[a]

INFLUENCE OF THE TEXTURE OF SOIL UPON THE YIELD OF CROPS.

The texture of the soil, as already pointed out, influences the climate of the soil in that it affects the water supply and the temperature, under which the crop is produced. It will be observed that the actual distribution of the rain water—the conservation of the water which falls and the supply of water to the crop—is regulated almost entirely by the physical characteristics of the soil, though modified to some extent by physiographic position. So far as the necessary water supply of crops is concerned, therefore, the crop is not dependent directly upon the rainfall, but upon the daily and hourly supply which can be delivered by the soil to the roots of the plants, whether the ultimate

[a] Johnson long ago pointed out that the application of 20 pounds of nitrate of soda to an acre of grass resulted in the crop removing from the soil considerably larger quantities of nitrogen than could be accounted for by that added. Similar observations have been made regarding potash and phosphoric acid, the explanation usually offered being that the added fertilizer acted as a stimulant to the plant, increasing the action of its root system upon the soil. But it would seem as reasonable to ascribe this effect to a physical or chemical action of the fertilizer upon the soil.

source of the water is from rainfall, irrigation, or seepage. The influence of the texture of a soil, regulating as it probably does the supply of moisture and, presumably, in connection therewith the supply of nutrient material, upon the yield of crops is strikingly shown in the cropping of the light sandy soils of the Atlantic coast which, because of the light yield of corn and wheat, are used almost exclusively for early truck; and in the use of the Hagerstown loam and Hagerstown clay of the Lancaster area, Pennsylvania, the Valley of Virginia, and the blue-grass region of Kentucky and Tennessee in producing hay and grain. For the same reason the Miami black clay loam of Ohio and Illinois is used for corn; certain soils in the Connecticut Valley for tobacco; the sandy soils of Virginia for bright-yellow tobacco; the clay soils of the same State for the heavy manufacturing and export types; and muck soils for celery, onion, cabbage, and peppermint.

The investigations of the Bureau, as has been shown, indicate approximately the same amount and the same proportion of plant food per unit of soil solution in these different types of soil. The physical characteristics of the soils, however, are very different. The Miami black clay loam is a heavy clay loam soil maintaining usually from 25 to 30 per cent of water. The Norfolk sand, of the truck area, is a coarse sand, maintaining usually about 6 per cent of water when in good condition for crop yields. The Miami black clay loam is the ideal corn soil of the Ohio Valley, and with good methods of cultivation yields of 60 or 80 bushels of corn per acre can be obtained in favorable seasons. Experiments have shown that about 300 or 400 pounds of water are required for the production of every pound of dry matter. The corn plant would presumably require as much water per pound of dry matter, whether grown upon the Miami black clay loam or upon the Norfolk sand, and if it were possible to produce a yield of from 60 to 80 bushels per acre on the Norfolk sand, it is probable that the same amount of water with its nutrient constituents would have to be supplied. The fact that an equal amount is not supplied ordinarily by the Norfolk sand unquestionably accounts for the very much smaller yield of corn, amounting usually to only 8 or 10 bushels and shows in a striking way the influence of the texture of the soil upon the yield of crops.

Hilgard[a] has called attention to an apparent exception to this rule in the production of good wheat crops in California on sandy soils and on heavy adobe soils. He explains this by stating that on the heavy adobe soils the roots penetrate to a depth of 2 or 3 feet, while on the lighter sandy soils they reach to a depth of 6 feet or more and so have a larger feeding ground. This, however, is under a very light rainfall where the wheat crop can be matured on the winter rain with no precipitation during the period of growth. It has always been recog-

[a] Agricultural Science, 7, 324 (1892).

nized that essentially the same results can be obtained in the East on light soils and on heavy soils, provided the season were just right, or irrigation were practiced. For example, very satisfactory crops of wheat are grown on the Norfolk sand on the low forelands of the Salem area, New Jersey, where the lands are well manured for truck crops and where the low position of the soil keeps it constantly moist. Very different results are obtained on the Norfolk sand on the higher lands where the soil is drier.

It appears that in our humid regions, where rain falls on the average every third day, although there may be an occasional dry spell of from ten days to several weeks, and where the soil is moist down to the subsoil, the crop is much more shallow rooted than in the West. In the early spring, which is usually wet from a constant succession of rainy days, there is but little incentive for the plant to send down a deep root system. The soils dry out quickly and the effect of a dry period of two or three weeks is very serious. This is illustrated forcibly by the common experience that if during such a dry period a lawn is watered, the practice has to be continued each day, or the crop is worse off than if the watering had not been begun. The usual method of watering a lawn wets the ground to a comparatively slight depth and surface roots develop, which must be constantly supplied with water or the plants suffer.

Numerous instances might be cited to show how marked the physical characteristics are in their effect upon crop yields when other conditions are equalized so far as possible, but the following will probably suffice to illustrate this point.

Atwater,[a] in his cooperative fertilizer experiments for the Department of Agriculture, gives the yield of corn on unmanured land selected for his experiments as follows:

Soil selected in—	Bushels.
Massachusetts	10.3
Connecticut	12.5
New York	16.3
Indiana	38.2
Ohio	40.0
Michigan	44.7

These soils were unquestionably under different climatic conditions, but presumably under about the same conditions of cultivation, and from the descriptions given of the several soils it would appear that the difference in yield is to be attributed mainly to the difference in the texture of the soils.

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[a] Fertilizers: Cooperative Experimenting as a Means of Studying the Effects of Fertilizers and the Feeding Capacities of Plants. Washington, Government Printing Office (1882)

Bloomfield and Hine,[a] in their work in Ohio, found yields of corn on unfertilized soils as follows:

In Vinton County 26 bushels on a sandy loam soil with a clay subsoil, resting on sand, overlying rock. On another farm in the same county 42 bushels on a clay soil containing a little sand, with a gravelly subsoil overlying the Coal Measures. On still another farm in the same county the yield was 84 bushels, on a heavy clay with clay subsoil underlain with sandstone and limestone shale. On a soil in Pickaway County 64.8 bushels were obtained from a black loam soil underlain with a blue clay subsoil, probably the Miami black clay loam. In Ashtabula County 19.7 bushels were obtained from a white or yellow soil, heavy and wet. In Adams County 28 bushels were obtained from a dry compact clay with a blue clay subsoil underlain with limestone. In Stark County a yield of 40.5 bushels was obtained from a clay loam. In Champlain County a yield of 57.1 bushels was obtained from a clay soil underlain with limestone. Here again it would appear that the difference in the texture, from what we already know of the effect of texture on the yield of crops, would be a sufficient explanation of the differences in yield.

The texture of the soil is the principal basis for the classification of soils in the soil survey, and taken in connection with the character of vegetation and the experience of farmers is undoubtedly a safe and reliable one for the estimation of the relative value of soils for certain crops and for determining the most efficient methods of cultivation. It is realized that the controlling effect of the physical properties of soils on crop distribution and production does not depend wholly upon the texture of the soil, as shown by the mechanical analysis, but that there are two other very important properties, the organic matter content and the structure of the soil, or the arrangement of the soil grains. Unfortunately no satisfactory method has been devised to determine this structure or its consequent effects. Not only is the character and yield of a crop adapted to a soil dependent upon the texture and structure, but upon the moisture which the soil can deliver to the plant to supply its needs.

It has been shown in previous publications[b] of this Bureau that the minimum amount of water a soil must contain before crops suffer from drought varies within very wide limits. In some of the light, sandy truck soils crops will continue to grow without apparent suffering when the soil moisture is down to 2 or 3 per cent, while in the black waxy soil of Texas a crop may suffer from lack of moisture with a water content of 25 or 30 per cent. The yield of crops is, of course, greatly different on such soils when in good condition.

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[a] Bul. No. 88, Ohio Agr. Exp. Sta., 1897.

[b] Buls. Nos. 1, 2, 3, and 9, Division of Soils, U. S. Dept. Agr.

That a soil may attain such a degree of desiccation as to actually draw water from the plant material has been clearly recognized by such an authority as Pfeffer,[a] who states that "if water is supplied through leaves or twigs a current may pass from these to the dry soil." This does not necessarily mean that the dry soil could draw water back from the living roots of a plant which had been growing in it previous to the drought, but this might be inferred.

In this connection two very interesting experiments have lately been performed in the Bureau. Cameron found that a porous cell having deposited in it a semipermeable membrane through which water can pass freely, but through which salts and certain organic substances, like sugar, can not pass readily, if filled with a strong solution of sugar and buried in a saturated soil, will draw water out of the soil through osmotic action. When this same cell, however, is buried in a soil short of saturation but yet in fair condition for plant growth, the soil will draw water from the cell against a calculated osmotic pressure in the cell of 36 atmospheres, or about 500 pounds per square inch. The movement of water out of the cell into the slightly moist soil is noticeable a few minutes after the cell is placed in the soil, and the movement is from the first much more rapid than would result from evaporation in the air from the surface of the cell. The enormous force of capillary attraction in a soil short of saturation is thus strikingly evidenced.

Briggs has devised an ingenious centrifugal machine to secure the moisture from a sample of soil. The soil is put into a cylinder rotating around a central axis and revolved at the rate of about 8,000 revolutions per minute. He finds that where the soil is moderately moist the amount of moisture in a sample can be reduced to about the point where the soil is in fair condition for plant growth. He can not, under these conditions, reduce the moisture content to a point where plants would actually suffer for lack of moisture. He calculates that the pressure developed at the surface of the cylinder, which tends to make the moisture fly out from the revolving sample, is equivalent to about 75 pounds per square inch, basing this upon the force acting on a gram of water spread out over a square centimeter of surface. From a given sample of soil he may by this method extract 50 cc. of water. From an equal quantity of another soil, having the same water content, he may be able to extract only 5 cc. of water, indicating a great difference in the amount of water that can be delivered at any point, in this case at the surface of the cylinder, under an enormously high pressure. In view of this we must conclude that a plant growing on one of these soils can have delivered to it, or can appropriate for its use, a far greater supply of moisture than a plant of the same kind growing on the other soil.

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[a] Physiology of Plants, Vol. I, p. 212; translated by A. J. Ewart (1900).

It is a fact that has been mentioned in previous publications of this Bureau that, so far as has yet been determined, the texture and chemical composition of the Susquehanna clay and the Hagerstown clay are identical. The former supports a scant and scrubby growth of pine and dwarf oaks and is considered generally a barren soil, while the Hagerstown clay is one of the most productive wheat and grass soils of the Eastern States. The normal vegetation of the Susquehanna clay is a desert growth of plants with thick waxy leaves turned toward the sun and with most of the other characteristics of desert vegetation. This indicates a desert condition—a lack of available water—and yet moisture determinations have repeatedly shown the actual water content of this soil to be at least as high as that of the Hagerstown clay. It seems reasonable to believe that the Susquehanna clay can not deliver to the plant a supply of water sufficient for the needs of agricultural crops, while the Hagerstown clay can supply an amount abundant for such delicate and sensitive plants as blue grass and timothy. It is thus seen that some of our cultivated plants will actually perish in the Susquehanna clay for lack of sufficient moisture, although a moisture determination would indicate the presence of an abundant supply. It is becoming increasingly evident that this capacity of a soil to deliver water is a very important and probably the most important factor in crop production, and this is a point which will receive consideration in the future work of the Bureau. The delivery of water from the soil to the plant must receive more consideration in future chemical studies of soils for the reason that it is the mechanism by which the mineral nutrients are supplied to the plant, and it is evident that if the delivery be small, the plant will suffer not only for water itself but also for the mineral food which the water supplies, even though ample quantities may be present in the soil solution, and in what would usually be regarded as readily available form. This point of view aids in understanding many of the discrepancies between chemical indications and actual crop returns in past work, and conclusively shows that a chemical study of a soil, which does not include as well a physical study along the lines here suggested, can not be expected to yield definite results.

THE INFLUENCE OF ROTATION ON THE YIELD OF CROPS.

The influence of rotation upon crop yields is probably as well illustrated by the Rothamsted wheat experiments as any which might be cited. The yield of wheat grown continuously without manure for fifty years has been reduced from 33½ bushels, the average maintained on the best fertilized plot, to 15 bushels. Where wheat has been rotated with roots, barley, clover, beans, or fallow, the wheat being sown every fourth year for forty-four years, without the addition of manure or fertilizers of any kind, the yield of wheat has not been

sensibly reduced; the yield, even where the roots were carted off and the land left in fallow, being 33½ bushels in 1883, as against 30½ bushels in 1851, 37⅜ bushels in 1855, and 35 bushels in 1859.

The yield of wheat in this same experiment, where mixed mineral and nitrogenous manures had been used in some part of the rotation, has not been sensibly larger. In this case, then, by a simple rotation and change of cultural methods from year to year with the change of crop, the yield of wheat has been maintained practically constant for forty-four years; whereas, the yield under continuous wheat culture has fallen to one-half in the same length of time. This decrease can be ascribed only to some physical change in the soil, to some chemical change other than the actual loss of plant food taken up by the crops, or possibly to the accumulation of disease germs, insects, etc., which, it is known, frequently occurs where rotation is not practiced.

The total quantity of plant food removed with the crops grown on the field in which crop rotation was practiced is probably not less, and presumably much more, than in the case of the wheat grown continuously with the average yield of 15 bushels per acre. It is not likely, therefore, that the decreased yield of the wheat grown on the continuously unmanured soil can be due to the amount of plant food removed by the crop. It will be remembered that the cultivation of wheat involves at most plowing in the fall and harrowing when the seed is put in, while for cultivated crops, plowing and cultivation continue throughout the growing season and that the root system of the crops used in the Rothamsted experiments on rotation differ greatly. It would be expected, therefore, that with such rotation and the much more thorough cultivation the land would be maintained in a different physical condition than where it was planted every year for a period of fifty years in an uncultivated crop like wheat, and it seems reasonable to look to this difference in the physical condition of the soil as a reason for the marked decrease in the yield of wheat grown continuously as compared with the yield of wheat grown in rotation with other crops.

THE INFLUENCE OF VARIETY OF THE PLANT ON THE YIELD OF CROPS.

One of the important factors influencing the yield of crops is the variety of seed used. Just why the variety should influence the yield to such an extent as it does has never been determined. It seems to be a question coming under the domain of vegetable physiology. It is a significant fact, however, that this influence of variety is not constant, but varies from season to season, indicating a relation between physiology, the physical characteristics and condition of the soil, and the character of the climate. This connects the question more or less closely with physical soil investigations, but no definite relations are

obvious from the experiments that have been carried on or from the experience of farmers.

The effect of plant variety on the yield[a] is strikingly shown in the case of potatoes grown upon the same soil and by presumably the same methods of cultivation reported by the Ohio experiment station.

The lowest yield of 145 bushels per acre was obtained from the Dakota; the Burbank gave 198 bushels, while the Puritan Early gave 425 bushels, and the White Elephant 498 bushels, with a large number of other varieties coming in between.

When the same varieties were used on different soils the Albino varied in yield from 87 to 322 bushels; the Crown Jewel from 88 to 462 bushels, and the Summit from 100 to 418 bushels, showing the effect of soil on the same variety of seed.

Another striking illustration is taken from the work of the Maryland experiment station,[b] giving the yield of 23 varieties of wheat in 7 consecutive years. A few citations will suffice.

In 1897 the lowest yield of 31.1 bushels was obtained from the Ontario Wonder; the highest yield of 49.6 bushels from the Beal.

In 1896 the Jones's Square Head yielded 29.6 bushels, and the Russel 38.9 bushels.

In 1895 the Garfield gave the lowest yield of 24.2 bushels, and the Extra Early Oakley the highest yield of 42.4 bushels.

In 1894 the Rocky Mountain gave the lowest yield of 33.3 bushels, and the Currell's Prolific the highest of 45.5 bushels, the next highest being the Garfield with 44.2 bushels, which gave the lowest yield in 1895.

In 1893 the Nigger gave the lowest yield of 24 bushels, and the Wisconsin Triumph the highest of 47.9 bushels.

In 1891 the Nigger gave the lowest yield of 7.5 bushels, and the Fultz the highest of 21.4 bushels.

In 1890 the Ontario Wonder gave the lowest yield of 4.6 bushels and the Dietz the highest yield of 21.2 bushels.

This shows the enormous variation due to variety and the further fact that this variation is not constant, and is due unquestionably to other factors of plant growth; possibly to seasonal changes, conditions of cultivation, or other influences, of which we know little or nothing. It also shows the enormous influence of the season as a whole on the yield of the different varieties.

It may be that these great variations, due apparently to variety, are really due to the condition of the preceding crop—the vitality and state of maturity at the time the seed crop was harvested—and the condition in which the seed was when the succeeding planting time

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[a] Experiments with Potatoes, Bul. Ohio Agr. Expt. Sta., second series, Vol. III, No. 1, January, 1890.

[b] Bul. No. 56, Maryland Agr. Expt. Sta., 1898.

came around; but so far as we now know, the differences were due to the kind of seed used, as influenced profoundly by the condition of the soil, which condition, as before stated, modifies climate. The yield was also directly influenced by the climatic factors usually recorded in meteorological observations. There seems to be indicated here, also, a direct relation between yield, the physical condition of soil, and the climate, with the variety of seed as a contributing factor.

THE RÔLE OF COMMERCIAL FERTILIZERS.

If the generalizations contained in this bulletin, to the effect that the soil moisture has sensibly the same composition in different types of soil and in soil under good and poor methods of cultivation, and that there is more of these fertilizing ingredients in all the soils reported in the foregoing tables than the plant actually needs be sustained, it may well be that the rôle of fertilizers requires other explanations than those now generally accepted.

There is no question that in certain cases, and in many cases, the application of commercial fertilizers is beneficial to the crop. The experience of farmers, the enormous sums expended for commercial fertilizers, and the many experiments carried on at the experiment stations prove that under certain conditions fertilizers are very beneficial in increasing the yields of crops. The fundamental idea under all of this work, however, has been that of supplying plant food in an available form; that is, adding to the supply existing in the soil. It is significant that other conditions of growth have so much influence on the yield that in but very few instances, even after long continued experiment, has it been demonstrated that any particular fertilizing ingredient or ingredients are required for any particular soil, and that even then the effect of the fertilizer varies so greatly from year to year that no specific law has been worked out, even for a particular soil, from which the fertilizing requirements could be deduced in any exact manner.

It is also significant that, in general farming, fertilizers are most useful in the early stages of the growth of plants, and the common practice is either to put the fertilizer in with the plant or to put it in at some time before the seed is planted. Very little effect is obtained in field culture in attempts to increase the value of a crop showing signs of inferior growth, by the application of fertilizers. This would indicate that the effect is early and immediate. In opposition to this may be cited the special cases of the application of nitrates to increase leaf development, potash salts to increase starch, and many similar cases, particularly in greenhouse culture, to hasten the maturity, to prolong the growth, or to produce artificial stimulation of certain plant processes. But the use of fertilizers in such cases is recognized as producing artificial and abnormal conditions.

In the cooperative experiments carried on by Atwater,[a] numerous cases are cited where phosphoric acid is said to be a regulating ingredient and the predominating factor in controlling crop yields one year, while it is more or less efficient in the same soil in other years, and is inefficient in many cases in the same soils in still other years. The same fact is brought out in regard to potash and nitrogen, and it is clearly and unquestionably demonstrated that the effect of fertilizers is dependent upon the season, it being so influential in one season as to be designated as a dominant factor in the yield of the crop, while on the same soil in a different season it has no apparent effect. It is not that the effect is one year greater and the next year less, which might be attributed to the previous application, but it is just as likely to be inefficient one year and the controlling factor the next year as it is to be a controlling factor one year and inefficient the succeeding year.

It has been possible by the methods outlined in the preceding pages to recognize an increase in the amount of soluble salts where fertilizers have been recently applied to the soil, but that these increases are not cumulative, and that they disappear with surprising rapidity has been amply demonstrated. So rapid, indeed, is the disappearance of added soluble minerals from the soil that the usual explanation of loss by leaching seems quite inadequate. This suggests the great probability that chemical processes are at work reducing the solubility of mineral components already present and even forming, synthetically, much less soluble mineral components involving the added constituents. In the truck soils of the Atlantic coast, where 10 or 15 tons of stable manure are annually applied to the acre, in the tobacco lands of Florida, and of the Connecticut Valley, where 2,000 or 3,000 pounds of high-grade fertilizers carrying 10 per cent of potash are used, even where these applications have been continued year after year for a considerable period of time, the dissolved salt content of the soil as shown by this method is not essentially different from that in surrounding fields that have been under extensive cultivation.

In England and in Scotland it is customary to make an allowance to tenants giving up their farms for the unused fertilizers applied in previous seasons.[b]

The basis of this is usually taken at 30 to 50 per cent for the first year, and at 10 to 20 per cent for the second year after application, but in the experience of this Bureau, there is no such apparent continuous effect of fertilizers on the chemical constitution of the soil.

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[a] Results of Field Experiments with Various Fertilizers, p. 68, U. S. Dept. of Agr 1883.

[b] For details regarding this practice the reader is referred to a recent publication by Voelcker and Hall, entitled, "The valuation of unexhausted manures, etc.," published by John Murray, London, 1903.

Even where large amounts have been used in the intensive cultivation of truck crops, the dissolved salt content is not sensibly higher in the following year than if nothing had been applied in the preceding season. This, also, points to an early and immediate effect of fertilizers and indicates that the fertilizing constituents may enter into some very slightly soluble combinations with the minerals of the soil. It is a premise of the generalization which is being here developed that when the solution equilibrium is disturbed by the addition of soluble forms of potash, or of phosphoric acid, for example, the solubility of the potash or phosphoric acid yielding components of the soil is forced back and the solution equilibrium is quickly reestablished. At the same time we have detected no constant decrease in the amount of soluble salts which could be easily detected with the methods used during the advance stages of growth of the crop, notwithstanding the considerable withdrawal there must be by the plants. It must therefore be assumed that the concentration of the soil moisture is easily maintained, and that as the salts are removed by the plants further quantities are quickly dissolved, thus keeping the solution at nearly the same concentration throughout the period of growth of the plant. One of the most significant facts shown in the present investigation is that the solution equilibrium quickly readjusts itself, at least as quickly as the plant disturbs it by withdrawing nutrients from the solution.

One possible explanation of the effect of fertilizers, which would be in entire accord with the hypothesis that has been formulated, is that the fertilizer is needed during the early period of growth when the root system is beginning to develop, that is, as the plant germinates and begins to feed upon the soil the root system has to be artificially nourished by a temporary increase in concentration as regards one or more constituents, whereas, when the root system is developed into a considerable volume of soil the plant will be quite capable of collecting all of these materials it may require. It is a fact, admitting of no argument, that fertilizers rarely take the place of efficient methods of cultivation and of cropping in increasing or maintaining crop yields. With the present methods of cultivation, the difference between the yield of 8 bushels of wheat per acre on the Cecil clay in North Carolina and 25 to 30 bushels per acre on the same soil in Maryland can not be adjusted by the application of any kind or any amount of fertilizers to the North Carolina soil. Some instances occur, however, where under more perfect methods of cultivation and cropping 25 bushels of wheat have been obtained year after year on the North Carolina soil, but this involved fundamental changes in the physical character and condition of the soil which would be amply sufficient to explain the difference in yield. From the fact that fertilizing effects are not constant in different seasons, and that it is well known that they vary with the character of the season, fertilizers being in some

years efficient, in other years inefficient, it would seem that there might be a relation between the physical conditions obtaining in the soil and the attendant climatic conditions, which relation could be affected by the addition of fertilizers. It would then seem possible that one effect of fertilizers might be in changing this relation of the soil to the soil moisture and the supply of the latter available for a crop, a supply which might be adequate one year, but not in another, without the addition of the fertilizers. It should be recognized, however, that both climate and fertilizers may have an effect on the crop directly, as well as indirectly through the soil, and that this latter may be of as great or greater importance than the former. Our knowledge of soil physics and plant physiology needs further development before we can positively assert much in this connection.

The investigations of the Bureau indicate that the beneficial effect of fallowing is not due to an accumulation of soluble plant food in the soil. It may be due to the storage of water; it may be due to a change in the physical condition of the soil, or to some bacteriological influence, but it is apparently not due to an increase in the amount of soluble plant food, as the soil can itself maintain the normal concentration, with ordinary plants withdrawing their nutrient salts at the ordinary rate of plant growth. Another fact of interest brought out is that the presence of humus does not apparently increase the dissolved salt content of soils. The influence of the humus appears to modify the structure of the soil and to regulate the water supply of the plant. This is, of course, in addition to its effect upon aeration and biological conditions.

The idea has been advanced, and has been held pretty consistently in former publications from the Bureau, that the ratio of the different substances in solution would have an important influence on crop production. Loew and his students have shown[a] that the relation of lime to magnesia has an important bearing upon the yield of crops, and suggestions of many similar relations can readily be found in the literature, but generally in these experiments extreme conditions have been maintained. The many analyses obtained in the investigations here recorded show wide variations to be unusual. They lend no support to this notion of the importance of the ratio of one plant food to another as affecting the yield or at least show it to be of minor importance. On the other hand, these results can not be cited as supporting the opposite view or so-called "law of minimum," generally attributed to Liebig—that is, that the yield is dependent mainly

[a] Relation of Lime and Magnesia to Plant Growth, by Oscar Loew and D. W. May, U. S. Dept. Agr., Bureau of Plant Industry, Bul. No. 1 (1901); Dependence of Yield on the Relation Between Lime and Magnesia, O. Loew, Landw. Jahrb., **31**, 561 (1902); Influence of Different Ratios of Lime and Magnesia on the Development of Plants, K. Aso, Bul. Coll. Agric. Tokyo Imp. Univ., **4**, 361 (1902).

upon that plant-food constituent that is present in smallest quantity as respects the need of the crop for it. We have examined a few cases, such as certain samples of the Galveston sand, which showed practically none of the several necessary mineral plant foods to be present and soluble, but neither will these samples in their natural state support any crop, being nearly pure silica, and as such can scarcely be regarded as soils. Practically, all soils were found to give a solution with a composition varying little from a normal, but even the exceptional soils showing extremely small quantities of one or more soluble plant-food constituents would still yield a fair crop if brought into good mechanical condition.

The idea now held by the Bureau as a result of these investigations is that the ratio of the nutrient elements in normal soils does not play a very important part in the yield of crops, or, to be more explicit, low yields are usually related to the physical condition and characteristics of the soil, and that it is only after these major controlling factors are changed and the yields thereby increased, that it would be necessary or profitable to consider this question of the ratio of plant foods. In other words, that it is only where all other conditions of plant nutrition and growth are satisfactorily controlled that the nutritive ratio can be considered an important factor and that the influence of this would be mainly seen in the quality of the crop rather than in the yield. In this effect it is analogous to the feeding of animals for work, fat, flesh, speed, or endurance, all of which can be sensibly controlled by the nutritive ratio only if other more important factors of growth and development, such as environment, etc., have been given due consideration. From our field investigations it does not appear that the low yield of 5 to 8 bushels to the acre on the Cecil clay of North Carolina, as compared with the 25 to 30 bushels of wheat obtained from the same soil under better methods of cultivation, can be due to a defective nutritive ratio in the first case, and that, therefore, this can not be in general an important cause of low crop yields, and that the subject of nutritive ratio can, therefore, safely be put aside for the present as of relatively little importance to the farmer, however great its importance may be to the horticulturist and floriculturist under the intensive system of cultivation practiced in those special lines.

CONCLUSIONS.

It would appear from the results given in this bulletin that plants can and do yield ordinary crops, though growing in media containing very small traces of all of the plant foods, while if the amount of these plant foods is increased a thousand times, as in the case of our alkali soils of the West, where potash, lime, phosphoric acid, and nitrates are frequently found in very large amounts, they are unable to give corresponding increases in the yield. On the contrary, the

yield from these arid soils under irrigation is no greater than that obtained from the soils of the humid regions, which contain far less of these mineral plant foods, provided the season in the humid region is just right, or that irrigation be practiced. Yields of wheat as high as 50 or 60 bushels per acre have been recorded in our Eastern States, and, as far as records go, such yields have never been exceeded under irrigation in the arid regions where most favorable moisture conditions are maintained and the soluble salt content of the soils is much greater than in the humid East.

The exhaustive investigation of many types of soil by very accurate methods of analysis, under many conditions of cultivation and of cropping, in areas yielding large crops and in adjoining areas yielding small crops, has shown that there is no obvious relation between the amount of the several nutritive elements in the soil and the yield of crops; that is to say, that no essential chemical difference has been found between the solution produced in a soil yielding a large crop of wheat and that in a soil of the same character in adjoining fields giving much smaller yields. The conclusion logically follows that on the average farm the great controlling factor in the yield of crops is not the amount of plant food in the soil, but is a physical factor the exact nature of which is yet to be determined.

It is not to be deduced from this that fertilizers do not frequently increase the yield of crops, but whether this increase is due to an actual increase of the plant food in the soil, to an early stimulation of the plant to enable it to get its roots out into a sufficient volume of soil, or to some physiological or physical effect is not altogether clear. As above stated, the effect of fertilizers on the quality of the crop is not specifically considered in this bulletin.

The results of these investigations also seem to indicate that the actual quantity of water a soil can furnish the plant, irrespective of the percentage of water actually present in the soil, has probably a very important influence on the yield. When the supply of water is inadequate to the need of the plant, as the water is a medium for the conveyance of nutritive solutions to the plant, it may well indicate not only a deficiency in the supply of moisture, but also of nutrient material contained in the water. It may be, moreover, that with an insufficient water supply, and consequently an insufficient food supply, fertilizers, by temporarily increasing the concentration of the solution, may increase the food supply of the plant; but as in this case also the obstructive factor is the purely mechanical function of delivering water from the soil to the plant, the problem is one to be handled by physical methods, and can not, in the nature of the case, be solved by chemical methods alone.

Again, while some variations occur in the composition and concentration of the soil solution, in the case of the great majority of cul-

tivable soils these variations are within comparatively narrow limits. The nature of the solution is but seldom permanently affected by the addition of ordinary mineral fertilizers, and it seems safe to say, therefore, that the concentration with respect to the mineral plant food constituents per unit of solution is approximately constant. Considering the wide variations in the percentages of water present in different soils, however, the amounts of dissolved plant foods in them may be quite different.

The conclusion seems justified that, although differences in the dissolved salt content, or in the concentration and composition of the soil moisture, may be a factor in the yield as well as quality of a crop, it does not appear to be a major one in determining or controlling the wide variations observed in crop yields on different soils. It appears further that practically all soils contain sufficient plant food for good crop yield, that this supply will be indefinitely maintained, and that this actual yield of plants adapted to the soil depends mainly, under favorable climatic conditions, upon the cultural methods and suitable crop rotation, a conclusion strictly in accord with the experience of good farm practice in all countries, and that a chemical analysis of a soil, even by these extremely delicate and sensitive methods, will in itself give no indication of the fertility of this soil or of the probable yield of a crop, and it seems probable that this can only be determined, if at all, by physical methods, as it lies in the domain of soil physics.

Finally, it seems appropriate in concluding this bulletin to quote the words, written a generation since, of one of the masters in agricultural science. Said Johnson,[a] in 1870: "It is a well-recognized fact that next to temperature the water supply is the most influential factor in the production of a crop. Poor soils give good crops in seasons of plentiful and well-distributed rain or when skillfully irrigated, but insufficient moisture in the soil is an evil that no supplies of plant food can neutralize."

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[a] How Crops Feed, p. 216.

APPENDIX.

Description of the Analytical Methods.

A description of the analytical methods used in this investigation is here given. It is not deemed advisable in this connection to go into the details of the work which has led to the adoption of these methods. But, though brief, it is believed the directions are sufficiently full to enable any one with ordinary analytical skill to follow them. It is proper in this connection to acknowledge the assistance of Messrs. George H. Failyer, J. F. Breazeale, and Atherton Seidell, of the laboratory of this Bureau, in devising and testing most of these methods.

APPARATUS.

In the operations to be presently described the apparatus required is for the most part quite simple, and such as any well-equipped laboratory can supply. For the preparation of standard solutions, a balance and set of measuring flasks is requisite. But for the actual determinations themselves a few burettes, pipettes, funnels, porcelain evaporating dishes, cylindrical bottles, a set of Nessler cylinders, and a camera are all that are necessary.

In the titration methods a narrow burette, with consequently wide scale divisions, is to be desired, and the orifice should be drawn out so as to deliver a very small drop.

A pipette delivering either 25 or 50 cc. and one capable of delivering 10 cc. but graduated to 0.5 cc., or smaller divisions, are desirable.

A few small funnels are also needed, with filter papers which fit accurately. In the potassium determination, for the separation and washing of the potassium chloroplatinate, a small carbon filter, fitted with a Hirsh or Witt plate and an asbestos mat; or, when laboratory facilities are at command, a Gooch crucible has been found more convenient than the ordinary funnel.

For the calcium and magnesium determinations, 8-ounce nursing bottles, fitted with tight rubber stoppers, are very satisfactory.

The comparisons in the photometric and colorimetric methods are facilitated by the use of a camera [a] consisting of a closed body to exclude side illumination, a slit at the top to admit a beam of light, and a row of circular openings of identical dimensions in a shelf upon which the comparison tubes rest. The beam of light is directed through the slit by a mirror, which may be set at any desirable angle and which moves on an axis parallel to the slit. The images of the circular openings are thrown on a similar adjustable mirror at the bottom of the camera. A series of Nessler cylinders is used, each about 2.5 cm. diameter cross section, 25 cm. high, and all as nearly uniform as it is possible to obtain them. One, intended to contain the standard, is fitted with a side arm just above the bottom and connected with an adjustable reservoir outside by means of a rubber tube passing through the side of the camera, so that the height of the column of liquid in the cylinder can be easily

[a] Similar to the device described by Whitson, Bul. No. 85, Wis. Agr. Exp. Station.

regulated. The liquid under examination is poured into one of the cylinders, which is placed in the camera over one of the circular openings, and beside the cylinder containing the standard. The height of the standard is then adjusted until the illumination, as shown by the images on the lower mirror, is equal. The height of the column of liquid in the cylinder containing the standard solution is then measured on any arbitrary scale which may suit convenience and which may be readily calibrated on the assumption that the amount in solution or in suspension is inversely proportional to the height of the column of liquid required to produce some definite illumination or color.

When working in the field or away from ordinary laboratory facilities, it will be found desirable to have a portable still for the preparation of pure water. A number of patterns are on the market, advertised for household purposes, and we have selected one which can be readily heated on an oil stove, and which can at the same time be utilized as a steam bath. We have also found it convenient to have a small copper water oven, the temperature of which can be kept quite constant over a range of about 15° C. by adding sugar (brown) to the water. The top of the water jacket is pierced to permit it being also used as a steam bath.

This whole outfit with reagents and standard solutions can be readily packed in small trunk and safely shipped from point to point as may be found desirable.

THE SOLUTION.

The water extract of the soil, prepared for analysis as described on foregoing pages of this bulletin, is free from mechanically-suspended material; but it is sometimes colored, due to dissolved organic matter, and for some of the determinations required must be decolorized until it compares favorably with pure water. This may be done by treatment with small quantities of lampblack, which has itself been freed from all traces of soluble substances.

The mineral substances to be estimated in a soil solution are bicarbonates (HCO_3), chlorides (Cl), sulphates (SO_4), nitrates (NO_3), phosphates (PO_4), silica (SiO_2) or possibly silicic acid (SiO_3), calcium (Ca), magnesium (Mg), and potassium (K). No satisfactory method has yet been suggested for determining sodium in such small quantities as are present in water solutions of agricultural soils. Other acids and bases are present in exceptional cases only and require special consideration.

BICARBONATES.

Normal carbonates (CO_3) are rarely present in water solutions of soils unless it be in the case of soils of "alkali" regions. Bicarbonates, the so-called acid carbonates (HCO_3), are always present in soil solutions. One portion of solution will serve for the determination of both these substances.

The method employed has been discussed at length by Cameron,[a] but for such dilute solutions as are here under consideration a two-hundredth normal (N/200) acid should be used. Those not familiar with the method will be enabled to use it by the brief directions given below.

A 25 cc. or 50 cc. portion of the solution is taken in a suitable vessel, a deep narrow cylinder with a clear bottom being preferable. Add phenolphthaleine. Should the development of a pink color indicate the presence of normal carbonates, titrate to disappearance of color with two-hundredth normal (N/200) acid. Then immediately add a drop of methyl orange and continue the titration. In the titration with phenolphthaleine as indicator the normal carbonates are changed to acid carbonates. In the second titration with methyl orange as indicator the acid carbonate originally present, with that formed from the normal carbonate, takes part in the reaction.

[a] Bul. No. 18, Division of Soils, U. S. Dept. Agr., p. 77 (1901).

Therefore the final titration less twice the first titration is the equivalent of the bicarbonate originally present. Should the phenolphthaleine test show the absence of normal carbonates, the titration for acid carbonates with methyl orange as indicator is carried out as just described.

Theoretically this method of determination is open to objection, because any silicic acid (but not silica) which may be present in the solution is included in the determination, and possibly phosphates and other weak acids. Long use of the method, however, leads us to believe that no serious errors occur from these sources, and that the practical difficulty of determining the end point of the reaction is the only one of moment. It is well to use as small an amount of methyl orange as possible and the eye of the individual analyst yet distinguish color, a matter that can be determined only with some practice, and to titrate to a comparison solution containing approximately the same amount of methyl orange and saturated with carbon dioxide. For this latter purpose a stream of air from the lungs of the analyst serves very well. After a little familiarity with the method remarkably good determinations have been made by men having no previous experience in such work.

CHLORIDES.

Chlorides are determined by titrating a portion of the soil solution, which must be neutral to indicators, with two-hundredth normal (N/200) solution of silver nitrate, using carefully purified potassium chromate (K_2CrO_4) as indicator. In this titration it has also been found advisable to use as little of the indicator as possible, taking the first decided change of color as the end point of the reaction. It has been found advisable to make these titrations in shallow porcelain dishes, as the color change is more marked and certain against the opaque white background than by transmitted or a mixture of transmitted and reflected light which one obtains when using a beaker or glass cylinder. A standard for comparison beside the test solution will generally be found helpful when the quantity being determined is relatively small.

SULPHATES.

For the determination of sulphates a modification of the photometric method of Hinds[a] and Jackson[b] has been employed, and instead of reading the depth of liquid containing suspended barium sulphate at which a standard source of illumination will cease to be seen, the test liquid is compared with a standard made from a solution of sodium sulphate of known concentration, by the addition of an excess of barium chloride or nitrate in the presence of a small amount of hydrochloric or nitric acid. It is of the utmost importance in order to obtain reliable results with this method that the standard solution and the test solutions should contain approximately the same amount of suspended barium sulphate, and that the precipitation of this substance should be made under as nearly like conditions of time, temperature, and concentration as possible. Further, the solutions should be so dilute that the precipitate is not seen as individual particles, only the opacity of the solution being apparent. Attempts to use suspended material other than barium sulphate, such as silica as proposed by Jackson, have not been found satisfactory when amounts are involved of the magnitude found in these soil extracts.

NITRATES.

The determination of nitrates is effected by means of the color developed on the addition of phenoldisulphonic acid, and then making the solution slightly alkaline with ammonia, and comparing it with that developed in a standard solution of

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[a] Jour. Am. Chem. Soc., **18**, 661 (1896); **22**, 269 (1900).

[b] Ibid., **23**, 799-806 (1901).

potassium nitrate with the camera and cylinders described above. This method is an adaptation of the procedure described by Wiley,[a] which was originally proposed by Hooker, who used carbazol, the substitution of phenoldisulphonic acid being suggested by Radeal.[b] It has been used for the examination of soil waters, both abroad and in this country, notably by King in his investigations at Madison, Wis.

In this determination, the comparison of the test solution with the standard is facilitated by the fact that with change in the quantity of dissolved material present there is not only a change in intensity or depth of color of the solutions, but also in tint as well; and, as is well known, the matching of tints is much easier for the ordinary eye than differentiating varying intensities of light.

The phenoldisulphonic acid is made by digesting 15 grams of practically anhydrous phenol with 92.5 cc. pure sulphuric acid, free from nitrates, and 7.5 cc. of water on a steam bath, or by allowing the mixture to stand for some hours. The material thus prepared is kept in a bottle with a close-fitting glass stopper, and not allowed to absorb water or other vapors more than can be prevented by ordinary careful handling.

The procedure we have found advisable is to carry 50 cc. of the aqueous soil extract to dryness in a porcelain dish on the steam bath. One cubic centimeter of the phenoldisulphonic acid and an equal volume of water is then added and the whole carefully stirred, warmed gently, and allowed to stand fifteen minutes. The solution is then diluted to about 25 cc. volume and made distinctly alkaline with ammonia water. When transferred to the cylinder for comparison in the camera, the assumption is made that the solution is diluted to a standard mark; but this is not necessary, for it has been found that the cylinder will give the same tint and intensity of color, no matter what depth it may have, so long as the actual amount of coloring matter remains the same. The color should be developed in the standard solution at the same time. It has been found that a standard containing two parts per million of NO_3 is the most generally useful for this work.[c] So sensitive is the method that it is essential that no fumes whatever of nitric acid should be allowed access to the solution while this work is in progress.

PHOSPHATES.

Phosphoric acid is determined by an adaptation of the method suggested by Lepierre,[d] Jolles and Neurath,[e] and more fully developed subsequently by Woodman and Cayvan,[f] Vietch,[g] and others, which consists in developing the yellow color produced by adding molybdic acid to a solution containing phosphates in the presence of nitric acid and comparing with the color produced in a standard solution of sodium phosphate treated in a similar manner. To 50 cc. of the soil extract there is added 3 cc. of solution of nitric acid (1 part concentrated acid to 5 parts distilled water) and the solution evaporated to dryness on the steam bath. The residue is taken up with a small quantity of water, nitric acid again added, and the whole thoroughly dried again to insure complete separation of silica. It is then taken up with water and washed through a small filter, if necessary. Three cc. of the nitric-acid solution is added, then 3 cc. of the molybdate solution,[h] and the whole is

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[a] Principles and Practice of Agricultural Analysis, vol. 1, p. 554.

[b] Chem. News, **60**, 261 (1889).

[c] If the concentration of the test solution be much greater than this, it is generally better to dilute an aliquot part with which to make the comparison in the camera.

[d] Bul. Soc. Chem., **15**, 1213 (1896).

[e] Monatshefte, **19**, 5 (1898).

[f] Jour. Am. Chem. Soc., **23**, 96 (1901).

[g] Ibid., **25**, 169 (1903).

[h] Prepared by dissolving 10 grams ammonium molybdate in 100 cc. water.

allowed to stand twenty minutes, and then compared with the standard in the colorimeter camera.

Silica is determined by reducing, by evaporation, a second portion of the soil extract to convenient volume, adding the nitric acid and molybdate solution, allowing it to stand at least an hour and comparing in the camera. The reading obtained, less that obtained for the phosphoric acid, gives the reading for silica. The equivalent of this reading for parts per million of phosphoric acid (PO_4) in solution, multiplied by the factor 0.41 gives the corresponding parts per million of silica (SiO_2).

Dr. Oswald Schreiner, of this Bureau, has suggested another modification of the method, for the purpose of shortening the time of manipulation, and avoiding the sometimes difficult and uncertain separation of the silica by evaporation of the solution. The method is founded on the empirical discovery that the same color is produced in a solution of a phosphate if nitric acid be added at the same time as is ammonium molybdate, or subsequently after some definite period; but that such is not the case with solutions of silica, the intensity of the color produced, by a subsequent addition of the nitric acid, being approximately one-half what it would be were the nitric acid added previously to or simultaneously with the ammonium molybdate. Briefly, the procedure advised is to add 5 cc. nitric acid solution (s. g. 1.07) and 4 cc. ammonium molybdate solution (50 gr. salt to a litre of solution) to 50 cc. of the test solution, allowing it to stand twenty minutes, and comparing with the standard phosphate solution treated similarly, obtaining a reading (A). To another 50 cc. portion of the test solution, add 4 cc. of the ammonium molybdate solution, allow to stand one hour, then add 5 cc. nitric acid and after twenty minutes compare with the standard, obtaining a reading (B). Under these conditions, the following equations hold:

$$\left.\begin{aligned} x + y &= \mathrm{A} \\ x + 2\,y &= 2\,\mathrm{B} \end{aligned}\right\} \text{ and } \begin{aligned} x &= 2\,(\mathrm{A}-\mathrm{B}) \\ y &= 2\mathrm{B}-\mathrm{A} \end{aligned}$$

where x is the reading due to silica, and y is the reading due to phosphoric acid. Schreiner independently found the factor for reducing the reading in terms of phosphoric acid (PO_4) to the equivalent in silica (SiO_2) to be 0.40 instead of 0.41 as determined by Veitch [a] and Seidell [b], a very satisfactory confirmation of the determination of this important figure.

POTASSIUM.

Potassium is determined, indirectly, by aid of the rose or pink color produced when an excess of potassium iodide is added to a solution of a platinic salt. [c]

For this purpose a portion of the soil extract is taken, usually 25 cc., though in the majority of cases 10 cc. would probably be sufficient, and carried to dryness with an excess of sulphuric acid. The dried residue is then cautiously heated over a free flame, thus volatilizing and driving off the excess of sulphuric acid, any ammonium salts which might be present, as well as organic matter. The residue is then taken up with water, slightly acidified with hydrochloric acid, platinum chloride to decided excess is added and the whole evaporated on a water bath to a pasty condition. It is then triturated with alcohol nearly saturated with potassium platinic chloride, washed six to eight time with the same, and then twice or thrice with 95 per cent alcohol. It has been found, however, that in the short time the alcohol is in contact with the precipitated potassium chloro-platinate no appreciable solution of the latter will take place in 95 per cent alcohol, and the use of the alcoholic potassium

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[a] Loc. cit.

[b] This laboratory.

[c] This method for the determination of potassium was suggested by Merrell [Jour. Am. Chem. Soc., **2**, 145, 1880], but no experimental evidence was presented with the suggestion, and so far as we are aware none has appeared elsewhere.

chloro-platinate solution is of doubtful value. It is of the utmost importance that this washing of the precipitate should be carefully executed. If a paper filter be used it should be of as small a size as practicable, and should, moreover, fit the funnel accurately, for should either funnel or paper protrude much above the other, there will be found a tendency to "crawling" and great difficulty in washing out the excess of platinum soluble in alcohol. In our work it has been found better to use Gooch crucibles, or narrow carbon filters fitted with Hirsh or Witt plates and an asbestos mat. Filtering should be aided by suction, either with the aid of an aspirator, or by the analyst's lips, and the filter sucked as dry as possible between each washing. After the alcohol has evaporated from the filter, the residue is washed through the filter with hot water into a cylinder or flask, which can be tightly stoppered, the total volume of filtrate being kept as low as 20 to 30 cc., allowed to cool, very slightly acidified with hydrochloric acid, a decided excess of potassium iodide added, and the containing vessel tightly stoppered and set aside for at least 4 hours for the maximum development of color. The solution is then compared in the camera with a standard made from a stock solution of a platinic salt of known concentration. In this determination the tint or "quality" of color is of great importance, and it is therefore necessary for accurate work that such concentrations of test and standard should be secured by proper dilutings that the actual comparisons should be made with solutions which do not vary widely in concentration. A standard corresponding to two parts potassium per million of solution is probably the most generally useful.

It has been found that if alcohol be added to the solution after the potassium iodide a brownish or yellow color is produced, and this has proved very annoying, since small quantities of alcohol left in the filter after washing the precipitated potassium chloro-platinate have sometimes so modified the color when potassium iodide was added as to prevent satisfactory comparisons. When the alcohol is present, on long standing, or within a few minutes if warmed cautiously, the solution acquires a beautiful yellow color, which is even better suited to comparisons than the pink color described above. It is not so intense a color, however, as the pink, and the latter is to be preferred when very small quantities are to be estimated, while the yellow is to be preferred when larger quantities are under examination. The yellow color, when it can be used, as in the case with most soil extracts, is probably more satisfactory and a very much more expeditious method.

CALCIUM AND MAGNESIUM.

Calcium and magnesium are determined by an adaptation of the well-known Clark [a] soap method modified by Winkler, [b] Grittner, [c] and others. The soap solution is made by adding 30 cc. oleic acid (c. p.) and 8 grams of caustic potash to 1,200 cc. of alcohol, and diluting to 2 liters with distilled water. This solution is allowed to stand three days, filtered, and diluted four times, maintaining, however, the proportion of alcohol to water in the diluted solution. This diluted or standard solution must be compared by titrating known solutions of calcium and of magnesium salts, and the ratio of the readings determined, since equal amounts of the solution do not correspond to molecular equivalents of calcium and magnesium salts. Moreover, the ratio varies somewhat with the concentration, so that it is preferable for exact work to so dilute the test solution that the portion actually titrated is always of about the same concentration. One cubic centimeter of the standard solution prepared as directed above will be found about equivalent to 100 cc. of a solution containing 2

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[a] Jahresber. Chemie, 1850, 608.

[b] Zeit. anal. Chem., **40**, 82 (1901).

[c] Zeit. für angewandt. Chem., **15**, 847 (1902).

parts per million of calcium and 0.9 part per million of magnesium. An "ammonium chloride solution" made by adding 10 grams of the salt to 38 cc. concentrated ammonia water, then diluting to 500 cc., and a "Rochelle salt solution" made by dissolving 100 grams of the salt with 6 grams of caustic potash in 500 cc. water are required. A portion of the soil extract (25 cc. or 50 cc.) is taken, depending upon the concentration, or is properly diluted, and a 50 cc. volume brought into a cylindrical bottle, which can be closely stoppered. Three cubic centimeters of the Rochelle salt solution is added, and then drop by drop from a small glass-stoppered burette the soap solution is added until by fifteen seconds' vigorous shaking a foam is produced which will persist for two minutes, when the containing bottle is laid upon its side. The end reaction can be quite sharply determined after some preliminary practice and is much facilitated by the change of the "feel" of the bottle when shaken as this point is approached. The reading thus obtained gives the equivalent for calcium alone. To a second portion of the soil extract, in another bottle, is then added 3 cc. of the ammonium chloride solution and another titration made. Should there be much magnesia or bases other than calcium present, a "false" foaming may be produced by the addition of the first few drops, and it is well to wait some minutes or until this first foaming has disappeared before proceeding with the titration as before directed. The magnesium reacts with the potassium oleate more slowly than the calcium does, and a longer time must be allowed for the foam to break before the reaction is judged to have come to an end. But when this time has been allowed the standing of the foam for two minutes after a thorough shaking for fifteen seconds will suffice. The difference in the reading of the two titrations, corrected by the proper factor, will give the equivalent of magnesium. It will be observed that the estimation of magnesium is subject to the experimental errors of two determinations, and as a matter of fact it can not be considered as altogether satisfactory when the proportion of magnesium to calcium is small, as is generally the case in aqueous extracts of soils. This fact has led Schreiner to propose the following procedure for the determination of magnesium, which experience has shown to be probably more accurate than the one just described:

To 50 cc. soil extract in an evaporating dish, add a drop of ammonia water and 2 or 3 drops of a solution containing 4 grams ammonium oxalate in 100 cc. and evaporate to dryness on the water bath. To the cooled dish then add 1 cc. of a solution containing in a liter 17.4 grams potassium phosphate (K_2HPO_4), 10 grams ammonium chloride (NH_4Cl), and 50 cc. strong ammonia water (s. g., 0.9). The whole content of the dish is thoroughly rubbed up with a glass rod and allowed to stand at least one hour. It is triturated five times with 5 cc. portions of a solution made up of 9 parts of pure water and 1 of strong ammonia water. Care should be taken to thoroughly wash the sides of the dish in this operation. The wash liquors are passed through a small filter and the filter and containing funnel washed until the filtrate measures approximately 50 cc. The residue in the dish is then washed once with cold distilled water. The entire filtrate is rejected and a clean vessel substituted beneath the filter. The residue in the dish is dissolved by 5 cc. nitric acid (s. g., 1.07), the solution passed through the filter, and dish and filter carefully washed with successive portions of 5 cc. hot water until the filtrate approximates 50 cc. The filtrate is cooled, 4 cc. of a solution containing 50 grams ammonium molybdate in a liter is added, and after twenty minutes the mixture is compared with a standard phosphate solution to which ammonium molybdate and nitric acid have been added. The magnesium is then readily computed from the equivalent amount of phosphoric acid actually determined.

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